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The Use of Gliding Cylclograms in the Biomechanical Analysis of Movements

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After a brief review of the optical recording methods of movements, the use of gliding cyclograms in biomechanical analysis of work is discussed. The gliding cyclogram method consists in recording of sequent positions of the moving body segments on photographic film which is transported at a constant speed. The very short exposures are provided by a rotating slotted disk which is fixed in front of the lens of the cyclograph. Examples of hammer stroke investigations and study of its efficiency, determination of optimum height for wood splitting block and an activity analysis of flax scutcher are given.

Since Leonardo da Vinci[10] in the last decades of the 15th Century started systematic observations of human and animal movements and Borelli[5] published his famous work, many scientists have contributed to the development of biomechanics.[9] However, genuine progress in the investigation and analysis of the effect of internal and external forces on human and animal bodies in movement and rest was made possible only in the last eighty years, after adequate and objective methods for recording movements were developed. The names of Muybridge,[26] Marey,[24] Fischer,[19] Gilbreth,[21,22] Bernstein[1,2,3,4] and Edgerton[18] should be mentioned as pioneers in this field.

An exact and objective method of recording movements has to fulfill the following requirements:

1. It should provide proper precision and bear a constant relation to the particular dimension chosen.
2. It should not interfere with and influence in any way the performance of the activity; i.e., it should not have back action.
3. It should have a sensitivity and range sufficient to pick up and record the changes of position of the joints and limbs under study.
4. It should permit easy interpretation and evaluation of the obtained data.

In accord with the above requirements, the investigator selects the proper system for transmission of the motion from subject to the recording or indicating device.

According to the kind of transmission used, four recording systems are possible. In the *mechanical system* the subject's movements are transmitted to a recorder by means of rods, levers, or pulleys; in the *pneumatic system* the transmission is accomplished by a change in air pressure; in the *optical system* the light rays transmit the effect of the movements, and in the *electrical system* the transmission is realized by a change in electrical current or voltage.

The mechanical and pneumatic systems only partially fulfill the above requirements for good recording, hence the optical and electrical systems of recording are usually the methods of choice.

OPTICAL RECORDING OF MOVEMENTS

Three basic optical methods are used for recording movements:

1. Motion pictures.
2. Interrupted light photography or chronophotography.
3. Gliding cyclograms.

This paper discusses each optical method and emphasizes the use of gliding cyclograms in the biomechanical analysis of movements. Figure 1 shows the optical methods.

Motion Pictures

Motion pictures are the most commonly used technique. Using mechanical or electro-mechani-

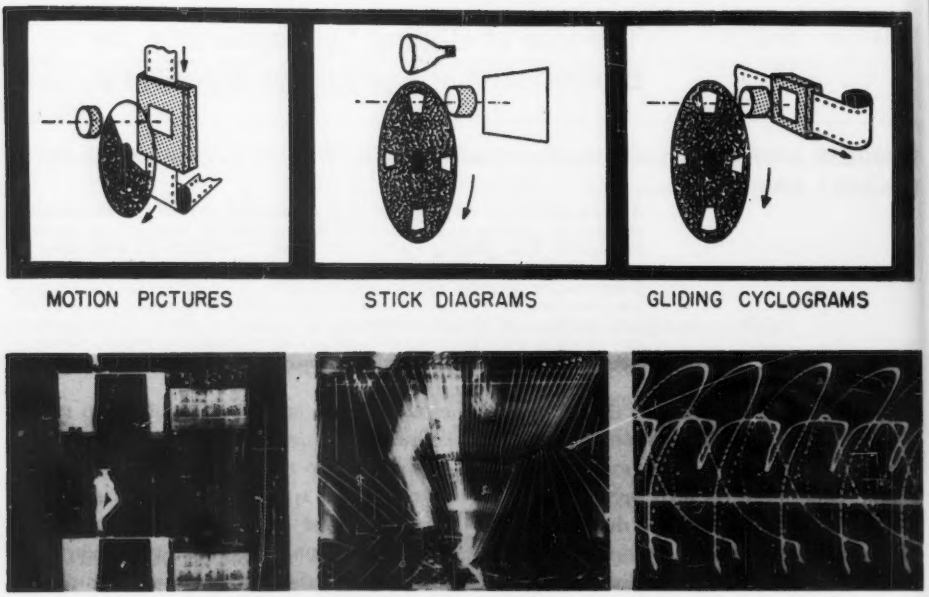
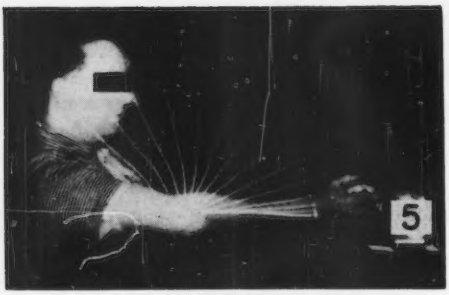
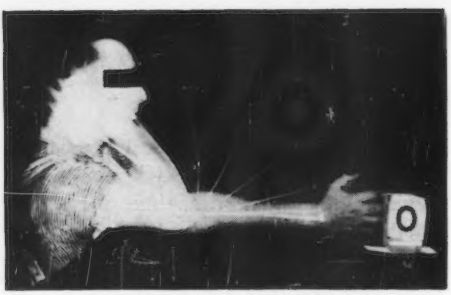


Fig 1. Optical methods of recording movements.



Restricted Motion (5 lb. Load)



Unrestricted Motion (Without Load)

Fig 2. Stick diagrams of forearm flexion.

cal means, the film is transported at a known, fixed rate past a lens and shutter. This technique is adequate for motoscopy but not useful for measurements, since in the reduction of data each single frame must be oriented in relationship to two of the three major coordinate axes as a frame of reference, which introduces possible sources of error. The orientation itself is very time-consuming. In addition, the film transport mechanism does not always respond at the same rate, so that the time intervals between consecutives frames vary significantly and contribute to the errors of measurement. The use of an electrical clock in the field of view for the determination of consecutive time intervals increases accuracy but also increases the data reduction time.

Interrupted Light Photography

When the activity to be recorded is not a repetitive (cyclic) one, as in the case of a jump, throw or a single forearm contraction, or is repetitive (cyclic) but progressing along a linear axis, as in the case of walking, interrupted light photography can be used.

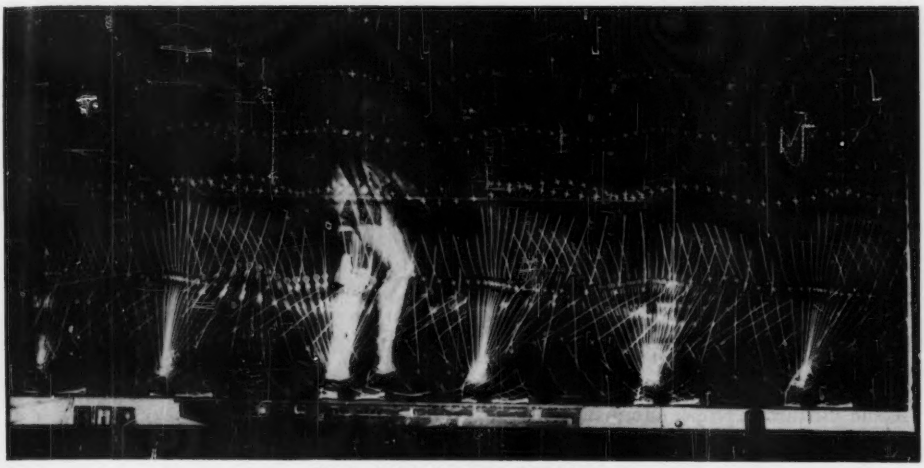


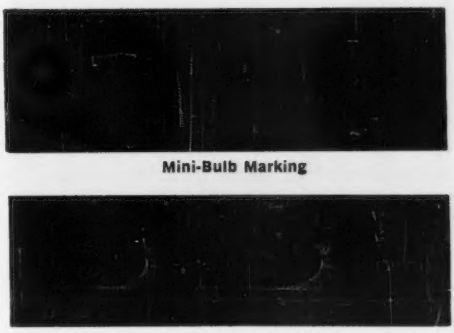
Fig 3. Stick diagram of walking.

Figure 2 shows single forearm flexions first without and then with the restrictive load. The load increases the total time of flexion and reduces the speed of forearm rotation as indicated by the smaller angular displacements during the equal time intervals.

The obvious advantage of this technique, as shown by Figure 3, is that it provides a complete pattern of a total movement, all of which may be recorded on one film. Reduction of data is greatly simplified with an enlargement, since the measures of vertical and horizontal displacement are taken directly from a single set of reference axes. The error then is only that which the analyst may make in measuring. The time intervals are as constant as permitted by the variation in speed of a synchronous motor.

Gliding Cyclograms

When the motion to be recorded is repetitive, or overlapping in a limited space, the interrupted light method cannot readily be employed, for the pattern of points cannot be distinguished as to occurrence in time. To overcome this difficulty in the 1920's Bernstein[1] in Russia, and Drillis[12] in Latvia, using an idea of Marey, independently developed the gliding cyclogram method. It is similar to the interrupted light method, except that here the film is transported across the field at a constant rate which may be varied to suit the particular activity being recorded. If, in a repetitive motion, a point on the moving body segment is returned to its initial position, the image on the cyclogram in the initial and succeeding instances will be displaced on the film by the distance the film has been transported in the elapsed time interval, as shown in Figure 4. The cyclogram method slightly increases the amount of work to be done in data reduction; the distance the film is transported in an interval of time, must always be subtracted from the measured horizontal displacement of a point. However the technique significantly increases the sensitivity and range of motion studies. The gliding cyclogram method has a special



Mini-Bulb Marking

Scotchlite Marking

Fig 4. Gliding cyclograms of arm flexion-extension.

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advantage in recording the motion of arm activities, many of which are repetitive and overlapping.

The cyclograph consists of a photographic camera with a lens and device for film transport as shown in Figure 5. The speed of film transport can be adjusted to the intended motion recording. Usually for 35 mm film the limits of transport speed are between ½ to 10 inches per second.

For recording, the cyclograph is strictly oriented in the horizontal and vertical plane, and in relationship to the plane of recorded movement. The cyclogram of the recorded movement should also furnish proper information on spatial and temporal dimensions. The space measure is usually provided by a 2 to 3 feet long scale with divisions in inches (or centimeters) or by two small electrical bulbs placed exactly 10 inches distant in the plane of the recorded movement. In case of three-dimensional recording, the scale serves also for the determination of the depth of the single points of the paths of movement.

The temporal measure is provided either by an intermittent light source or by a rotating disk light interrupter. As intermittent light sources, small electrical bulbs may be used. The current is interrupted at equal time intervals, or electronic strobe light flashes may be used. Since the current interruption technique does not furnish distinct sharp points, it is difficult to obtain exact measurements. The technique is now seldom used. The stroboscopic light flash technique also has disadvantages. First, the overlapping of consecutive pictures, and second, the strong flicker effect in some subjects significantly interferes with the performance. By the interrupter technique, the lens shutter is kept open, while a slotted disk is driven at the desired speed by a synchronous motor either directly or through a gear or pulley system. The disk rotates before the lens in such a way as to admit and exclude light alternately. The speed at which the disk rotates together with the number of slits in the disk determine the time interval between exposures. The width of the slit (i.e., the size of the angle included in the slit) and the rotation

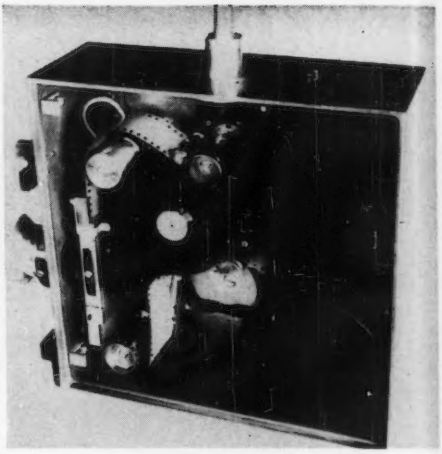


Fig 5. The cyclograph.

speed of the disk determine the exposure time.

In our motion studies at New York University, the light is supplied by a single photoflood bulb such as the GE narrow-beam (18-20°) RSP-2 500 Watt photoflood fixed close to the lens. The highly reflective Minnesota Mining Co. Scotchlite (N° 31 Silver W/A tape) is attached to the subject's joints and limbs which are to be photographed. Instead of Scotchlite markers sometimes miniature electric bulbs are used. The interrupter disk usually rotates at 25 rps and has one to four slits in it, so that from the Scotchlite markers reflected, light beam can be interrupted 25, 50, 75, or 100 times per second. In some special cases, up to 400 interruptions per second are used. If the interrupter rotates at 25 rps then the total angular displacement during one second is $360 \times 25 = 9000°$. Hence for exposure time of a $\frac{1}{1000}$ of a second, the slit's width should be 9°, but for $\frac{1}{1286}$ it is 7°. For reduction of data, the processed film is projected on a graph paper and the points and lines are marked with pencil or fixed photographically. To avoid distortions and assure higher accuracy, it is recommended that the same long focal length lens and a 1:1 scale be used for both recording and projection.

It should be noted that the above-mentioned methods have been used for three-dimension recording of movements. This is accomplished by:

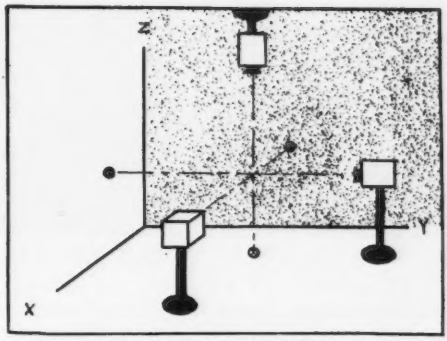
1. Three synchronized motion picture cameras, one for each of the reference planes of motion (University of California, Berkeley),[17]
2. Two still cameras or synchronized motion picture cameras with parallel optical axes, and
3. Two cameras or gliding cyclographs with a 90° angle between the crossing optical axes as used by Drillis,[13] or one camera and a 45° mirror as used by Bernstein.[2]

BIOMECHANICAL ANALYSIS

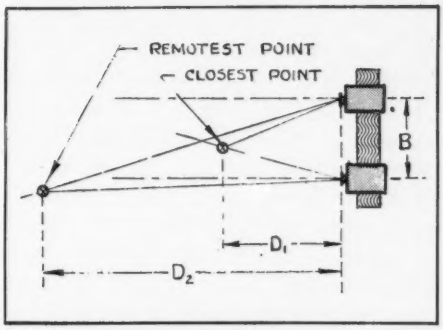
Normally each movement has a pattern or harmonious structure which can be submitted to a biomechanical analysis in terms of temporal, kinematic and kinetic factors.

Usually analysis of a given movement starts with the study of its time pattern, as indicated on the recorded cyclogram. The temporal pattern consists of two or more distinct phases which fit into the whole. For example in hammering, each single stroke has a lifting and a stroke phase; in filing, a cutting and a return phase; in walking and running, each stride has its swing and stance phase. The ratio of these phase times is an excellent indicator of structural changes in the pattern of movement. Besides the mean value, limits and range of the rate or cadence (tempo) of movements are determined. Moreover, the variability coefficient and index of motility are good indicators for temporal characterization of a repetitive or cyclic movement. The temporal pattern of movement is very sensitive to variations in the operators physical and psychological working environment. So the operator's fatigue and discomfort can be discovered in a change of the temporal pattern of movement.

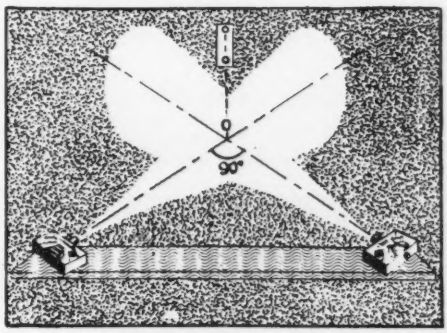
N. Bernstein[4] in his studies of abnormal movement found that in some cases the important symptomatic deviations from normal pattern have a period of only 0.1 seconds. The use of gliding cyclograms permits the resolution of mo-



RECORDING BY THREE SYNCHRONIZED MOTION PICTURE CAMERAS



RECORDING BY TWO CAMERAS WITH PARALLEL OPTICAL AXES



RECORDING BY TWO CAMERAS WITH A 90° ANGLE BETWEEN THE OPTICAL AXES

Fig 6. Methods of recording movements in three dimensions.

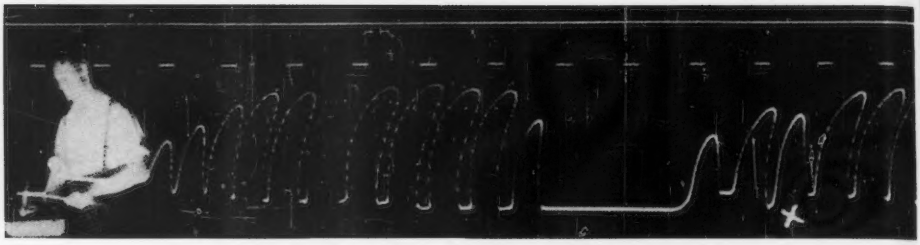


Fig 7. Gliding cyclograms of nailing.

tion into very small time increments. Thus the method can be successfully applied to investigations of normal and pathological motions.

Kinematics

The purpose of bio-kinematic analysis is discovery of the functional interdependence which exists among the three variables (x, y, z) of space and the one variable of time (t) in the given movement of a body, without taking into consideration the forces causing the motion. For biomechanical investigation, we assume that the segments of the human body are rigid, not extensible, their relative location does not change, and their motions are limited to rotations about an axis or point.

The path of movement may be either a space curve or a plane curve. In most cases only the simpler plane curves are recorded and analyzed. The problem of kinematics of motion of a rigid body is solved if it is possible to relate its instantaneous position to the selected system of coordinates.

In the kinematic analysis the shape, size, and position of the motion path in the plane or space are studied. From the recorded displacement curves the location of singular points can be measured. Curves of displacement vs. time can be plotted, or a system of empirical parametric equations can be computed. The velocities and accelerations are then determined by graphical or numerical differentiation.

The gliding cyclogram of nailing as shown in Figure 7 indicates the number and magnitude of sequent hammer strokes needed to drive a nail into a wooden block. The miniature electric bulb is fixed at the center of gravity of the hammer. The two straight lines at the top are spatial and temporal scales. The scales are formed by two miniature electric bulbs fixed exactly vertically at a 20 cm. distance. A steady current is supplied to the upper bulb; the lower bulb is lit only one-fourth second in each second. The gliding cyclogram shows how the amplitudes of hammer strokes in the initial phase (5 strokes) increase in size, then stay steady for five strokes until the nail is driven in, and the last stroke which has no purpose but is simply an automatic closing link for the total work-period. While driving the second nail, the second stroke does not hit the head of the nail. The third stroke is out of pattern but still well aimed at the nail's head.

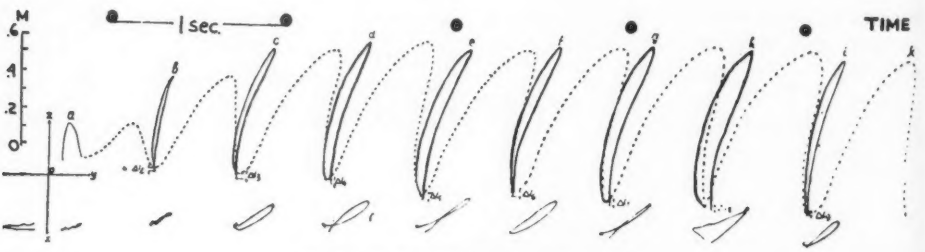


Fig 8. Gliding cyclogram conversion.

The spatial pattern of gliding cyclograms enables us to discover the symptoms of fatigue and disease in movement. In extreme cases, we are able to follow the gradual disintegration of the motor pattern. Similarly, the cyclograms show the build-up of the pattern in training and reconstruction of movements during recovery from disease.

We assume that the gliding cyclograms of performance of different human activities can provide profound and very useful information for ergological and psychomotor studies.

For nailing analysis[14] we used three-dimensional recording with two cyclographs fixed at a 90° angle between the crossing optical axes. Both sets of gliding cyclograms were then converted to still cyclograms as shown in the Figure 8. From the still cyclograms the location of single points on the paths of center of gravity in space were determined.

Figure 9 shows the spatial analysis of the hammer stroke movement and represents the change of the three coordinates vs. time of the center of gravity during one stroke. These curves can be described by equations which are determined by harmonic analysis or some other method. From these curves the velocity and acceleration projections on the axis of coordinates may be determined by graphical or numerical differentiation. The magnitude and direction of velocity and acceleration vectors can then be found.

Kinetics

Bio-kinetic analysis deals with the study of the change in the motion of a rigid body produced by an unbalanced force system, and the means for determining the forces required to produce any desired change in its motion. The problem of the kinetics of motion of a rigid body is solved if it is possible to determine the acting forces from the laws of motion and the known mass of the body, the location of the center of gravity, and its mass moment of inertia.

For bio-mechanical analysis it is very important to obtain accurate data on the mass distribu-

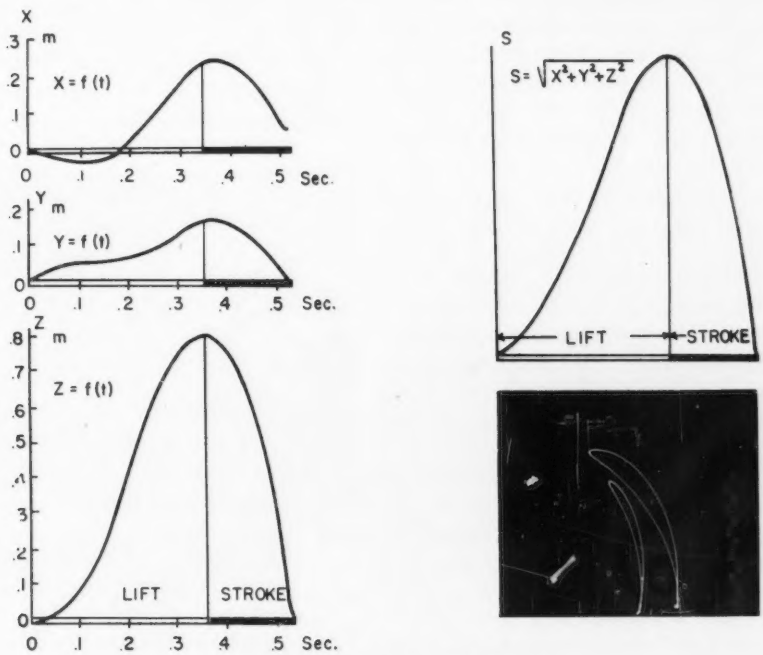


Fig 9. Hammer stroke analysis.

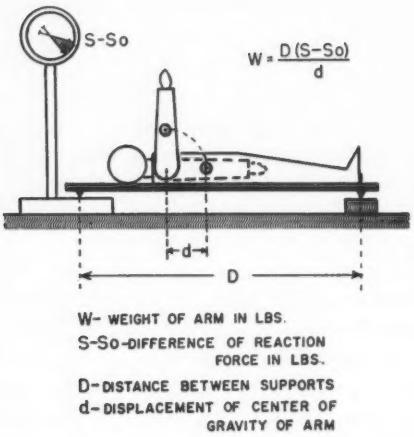


Fig 10. Determination of arm weight of a living subject.

tion of the human body, the location of the center of the mass, and the mass moment of inertia about the center of mass. There are several more or less accurate methods in use.

The volumetric methods of Weinbach,[28] Salzgeber,[27] and Dempster[11] are based on the determination of the segment's volume and assumption that the density of the human body is uniform overall or in the particular body segment.

At present the most commonly used method is that using Fischer's or other coefficients. Harless,[23] Braune[6] and Fischer, Bernstein and recently Dempster, established coefficients for expressing the relative masses of the segments compared to the body as a whole, and the location of centers of mass and radii of gyration of the segments as proportional parts of the length of the segment. The data were obtained from measurements on frozen human corpses.

To determine the weight of body segment of a living subject, we use the *method of reaction change.* Figure 10 shows these determinations. The subject lies on a plywood board with two iron edges under it. One edge rests on scales and the other edge is supported by a wooden block. First the reaction force is measured when the arm is located horizontally, then when it is raised 90° and the projection of the mass center of the arm passes through the shoulder joint.

The difference of the two reaction forces (S-So) and the distance (d) of the shift of the projection of the center of mass, (according to Fick and Fischer, the center of mass of the whole arm is located close to its elbow joint), enables us to determine the weight of the arm, W, as shown in Equation 1

$$W = \frac{D\,(S\text{-}S_0)}{d} \qquad \text{(Eq. 1)}$$

where D is the distance between the edges of support.

Figure 11 shows the set-up for determination of the mass moment of inertia of the forearm. The subject's upper arm is fixed horizontally on the table. He exerts a pull against a cord which is attached to the arm at the wrist joint. The cord is connected to a tensiometer which records the force of pull. With a strong pull the subject breaks the cord. The cyclograph records the movement of the accelerated flexion of the forearm after the break, so that it is possible to determine the angular acceleration (a′) of the arm. The pointer of the tensiometer shows the force of pull (F) at the instant the cord breaks. The distance between the elbow joint as the center of rotation and the middle of the wrist band (d)

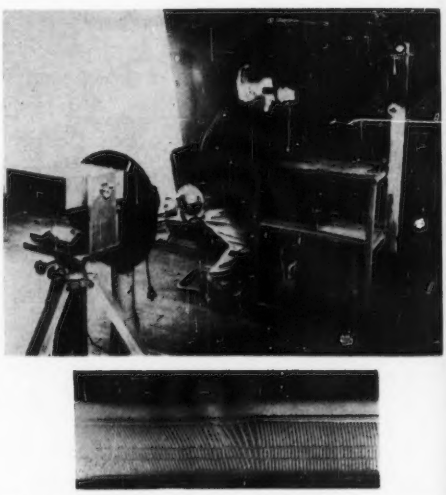


Fig 11. Determination of mass moment of inertia.

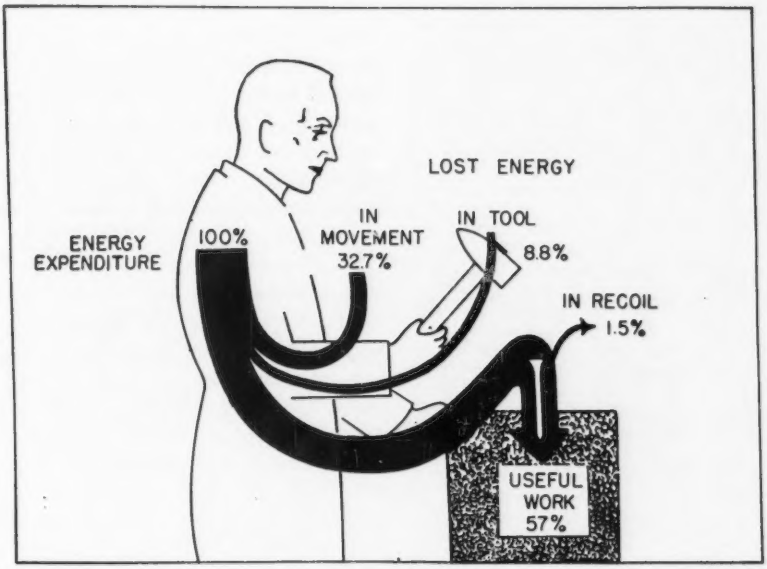


Fig 12. Mechanical efficiency of a hammer stroke.

is measured before the test, and can also be easily determined from the cyclogram. Then the mass moment of inertia (I) is determined from following Equation 2.

$$I = \frac{Fd}{a'} \qquad \text{(Eq. 2)}$$

The angular acceleration (a′) can also be determined by an electrical accelerometer.

The velocity and acceleration as well as data on the angle between the gravity line and direction of velocity obtained from gliding cyclograms and the known magnitudes of weight and mass moment of inertia permit the determination of the power developed by a moving body and the work performed.

Figure 12 shows the mean values of energy losses in accomplishment of the stroke movement, in the hammer and in recoil for eight hamer strokes used to drive a 6 inch long nail in a wooden block. The net efficiency of these strokes is only 57%.

The gliding cyclogram method permits us also to find the optimum height of a block for wood splitting.[15] After a number of axe strokes are recorded, the mean kinetic energy curve is plotted and the location of most effective height determined. Figure 13 shows that in this case the block height should be raised to increase the efficiency of the axe stroke.

Finally, the gliding cyclogram can be very useful in activity analysis. The methods and techniques used by human engineers for getting answers to practical problems are multiform. Job activity sampling and analysis is one of them. It means systematic observation of the operating system during proper time intervals. There are two possibilities, either the entire job or only part of it is observed.

The studies of the operations of navigators and radar operators by Christensen[7,8] and McFarland's and Moseley's[25] studies on bus drivers deal with entire job analysis; Fitts, Jones and Milton[20] studies on aircraft pilots' eye movements during instrument landing represents an activity analysis of part of a job.

Figure 14 shows activity analysis of a flax scutcher during an 8-hour work day.[16] From the total time only 9900 seconds were used for actual scutching and this time was subdivided in twelve work periods. The average number of strokes

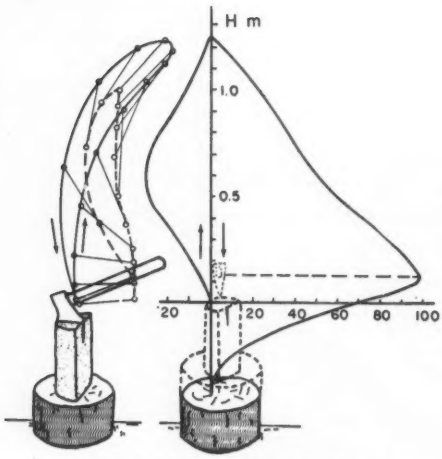
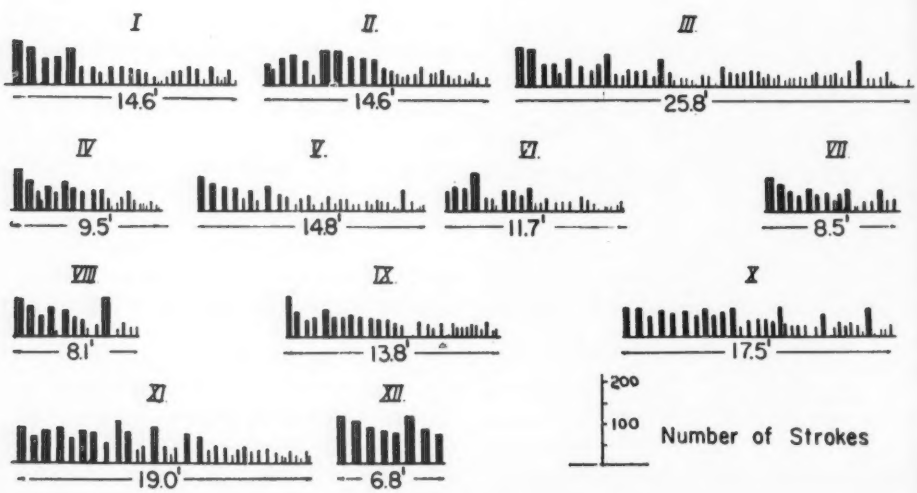


Fig 13. Optimum block height.

per one work period was 957. The biomechanical analysis determined that the mean work per stroke was 5.4 meter kilograms and the total mechanical work done during the actual scutching was 61,625 meter kilograms. The mean power developed was 6.22 m-kg/sec, or approximately 0.082 horse powers. The activity analysis can be time consuming, but it provides the possibility to pick out strokes or other movements from potentially high and low activity periods for biomechanical analysis and comparison.

In conclusion, we would like to suggest the use of the gliding cyclogram method as a sensitive and efficient tool for biomechanical and ergological analysis of human movements.

Fig 14. Activity analysis of a flax scutcher.



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Educational Programs in the Human Factors Area

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This paper summarizes trends in the development of university programs in the human factors area. Several examples are described briefly.

Five years ago a survey[1] of Departments of Industrial and Mechanical Engineering demonstrated that only twenty departments of one hundred and four answering had courses available in the human factors area. In eleven institutions the courses were offered in the Department of Psychology. Five were in Industrial Engineering, two in Mechanical Engineering, one in Engineering Administration, and one in General Engineering. In no institution was there an organized Human Factors program leading to a degree either in engineering or some other department.

In the last five years undoubtedly a considerable number of other departments have added courses in this area. No attempt has been made to conduct a follow-up survey. However, when the original questionnaires were collected, a number of additional institutions indicated that they were making plans for such a course. In recent years there has been greatly increased interest in the human factors area. These facts suggest that it is almost certain that the number of offerings has increased.

It is the purpose of this paper to report briefly the nature of some of the recently developed programs leading to degrees in the human factors areas, and to suggest something about the trend that seems to be developing. To secure information a number of universities in which programs in the area of human factors engineering were being organized were asked to describe the programs. In addition, the writer participated in a symposium on the training of Engineering Psychologists at the September, 1958, meeting of the American Psychological Association. The reports by the members of the symposium and the discussion which followed provided several interesting indications of the probable development of this important field.

GENERAL TRENDS

In general, there appear to be developing two types of programs. The first is a graduate program in psychology or physiology leading to the Ph.D. degree. These programs are basically research oriented and do not differ greatly from the traditional Ph.D. programs in the respective areas. The student is expected to have sufficient contact with courses in engineering to be able to fit into the requirements of the engineering situation. In addition, a great many such students will have practical experience in industry. A considerable number of them will have had undergraduate degrees in engineering or the physical sciences before entering into graduate work. The psychology programs, for example, frequently combine experimental methodology with industrial psychology. The term engineering psychologist seems appropriate for a person trained in this way. Such an individual is likely to find his role in industry in research and development programs and is most likely to be happy while conducting experimentation rather than when providing consultation. In addition he may be called upon to teach courses in Schools of Engineering or in other departments.

The second type of program is more specifically in the engineering departments. Human factors courses are offered to engineering students as part of their degree curriculum. In some instances the programs lead to Bachelor of Science

degrees and in others to Master's degrees. The graduate of such a program is appropriately called a human factors engineer since his basic training is in engineering. The curriculum is obviously similar to that of industrial engineering. As a matter of fact, in some instances it is part of the Department of Industrial Engineering. On the other hand it usually calls for greater emphasis on basic psychology and physiology and for more concern with man-machine systems and man-machine interactions. Such training should enable the human factors engineer to provide specialized services on an equal footing with other engineers.

EXAMPLES OF PROGRAMS

Following are brief descriptions of courses in the human factors areas offered at various universities throughout the country. The list is far from exhaustive since no attempt has been made to survey all institutions. The summaries may be considered examples of programs in existence or being planned. In the writer's opinion other universities that have, or develop, such programs would provide a useful service if descriptions of their programs were submitted to the Human Factors Journal for publication in the future issues.

University of California at Los Angeles

U.C.L.A. has offered courses in the area of human factors engineering since 1946 under the title of "Biotechnology". Biotechnology is defined as the study of the man-environment-equipment relationship as it applies to engineering planning and design. A number of undergraduate and graduate courses specifically in this area are offered in the Department of Engineering.

The program is planned to offer degrees to two types of students: those in engineering and those in psychology. Both plans are based upon core science training in mathematics and statistics, physics, chemistry, physiology, and psychology. The engineering degree candidate will graduate as a human factors engineer with a Bachelor of Science degree. He may go on to complete a Master of Science or a Ph.D. degree in human factors engineering. The psychology student will receive a Bachelor of Arts, Master of Arts or Doctor of Philosophy as an engineering psychologist.

Harvard University

The Guggenheim Center for Aviation Health and Safety at Harvard University, in addition to its program of basic research and its function as a clearing house for technical information on aviation health and safety, provides training in the human factors area. Essentially a graduate program, it is intended to give "advanced training for physicians, biological scientists and aeronautical engineers in problems involving aviation health and safety." Emphasis is placed on the field of human factors in aircraft design.

The Johns Hopkins University

An undergraduate student in industrial engineering at The Johns Hopkins University may specialize in any one of five areas: accounting, human engineering, labor relations, statistics, or operations research. The sample program in the human engineering area lists, in addition to basic science and mathematics, several courses in engineering, including machine design, additional courses in engineering psychology and a number of courses in experimental and general psychology. It is a four year program leading to the degree of Bachelor of Engineering Science. A program for the Doctor of Engineering Science degree in industrial engineering is being planned. It will permit emphasis in either operations research or human engineering.

University of Illinois

A doctoral program in engineering psychology is offered in the Department of Psychology. It is planned as a four-year graduate program including one year of internship involving research or applied work in an engineering psychology laboratory or in an engineering laboratory. The graduate is expected to be well grounded in experimental and quantitative methods and in such areas of psychology as perception, human learning, and communication. In addition, his training will include experience in a relevant

branch of engineering. He is advised to take a minor in engineering, mathematics, or physics, or a combination of the three. Engineers who enter this program are required to make up deficiencies in psychology in order to proceed toward a graduate degree in engineering psychology.

University of Massachusetts

Provision has been made in the Department of Psychology for a program in "Experimental-Industrial Psychology." In addition to being trained as an experimentalist the psychologist is expected to have training in psychological and physiological aspects of man as part of the man-equipment-environment system. He is also expected to have thorough training in physical sciences. Four specialized courses in industrial psychology deal with various aspects of the human factors area. In addition a seminar is offered which permits emphasis on selected topics in the area. Each student is expected to engage in research and is required to take a practicum involving actual work in an industrial setting. This is a graduate program leading to the Master of Science or to the Doctor of Philosophy degree.

New York University

Graduate training related to the field of human factors is offered at New York University in the Department of Industrial and Management Engineering, and in the Department of Psychology. Both Departments offer Master's and Doctor's degrees. Relevant courses of study in the Department of Industrial and Management Engineering include production methods, systems design, operations research, and human engineering. The offerings in the Department of Psychology include sequences in experimental, physiological, and industrial psychology. Depending on his interests and background, a student may matriculate in either Department, and combine his studies there with appropriate courses in the other Department.

Purdue University

At Purdue courses are offered in the human engineering area to students in psychology and to those who have majors in engineering. Graduate students majoring in the fields of industrial or experimental psychology may take several basic courses in the Department of Psychology including various courses in experimental procedures and statistical analysis. In addition, such courses as Physiological Psychology, Psychology of Work Efficiency, and Experimental Psychology may be supplemented by courses in the Biological Sciences Department including one entitled "Biological Factors in Engineering Design." Graduate students in engineering may minor in psychology. Both undergraduate and graduate engineers have available one or more courses related to human engineering offered in the Psychology Department or in the Biological Sciences Department.

University of Southern California

Several courses in the School of Engineering and in the Department of Psychology are offered as supplements to engineering training. These courses are composed largely of graduate engineers employed in local industry. No degree program in human factors engineering has been established. The Department of Psychology offers a Ph.D. program with special emphasis in the area of engineering psychology. This program is a combination of experimental and industrial psychology and requires supplementary courses in engineering.

Tufts University

At Tufts University a two-semester course in engineering psychology has been offered for several years. It is at the undergraduate level and is offered in both Liberal Arts and Engineering. Master's degree students in experimental psychology have done research on applied problems which has enabled them to secure employment in the area of engineering psychology. Consideration has been given to a Ph.D. program in Applied Experimental Psychology or Engineering Psychology. Such a program does not now exist, however.

Tulane University

The situation at Tulane University is quite similar to that at Tufts. An undergraduate lecture course in human engineering is offered primarily

for Junior and Senior students in the Departments of Electrical, Mechanical, and Chemical Engineering and fifth-year students in Architecture. Consideration has been given to the possibility of extending the offerings in the human factors area in such a way as to lead to undergraduate or graduate degrees.

PROGNOSIS

It is obvious from the foregoing examples that no consistent pattern of training in the human factors area has emerged. However, there appear to be trends from which such a pattern may be predicted for the future. In brief, they indicate the human factors engineer will be trained in engineering with supplementary courses and experience in psychology and physiology. Degrees offered are likely to include the Bachelor of Science, Master of Science, and the Doctor of Philosophy.

At the present time the Ph.D. program in engineering psychology has been developed at a number of institutions. It is probable that such programs will continue to emphasize experimental methodology and basic psychological principles with some supplementary work in engineering. Some master's degree programs in engineering psychology already exist. It is probable however, that most students who prefer a master's degree rather than the Ph.D. program will be advised to specialize in the area of human engineering in an engineering school. This is, in part, due to the fact that a number of states now restrict the use of the title *Psychologist* to persons holding the Ph.D. degree.

A similar program in Engineering Physiology could well be developed at the graduate level. No such program has been described. However, it is probable that students who receive the Ph.D. in Physiology with emphases particularly on sensory and skeletal muscle function would be well qualified to serve industry and to do research in this area.

In general, it should be re-emphasized that the opportunity for research and service in the human factors area is too great and too broad to be served by any single narrowly trained specialist. There is still convincing evidence that the best solution to the human factors problem in engineering is the team approach employing the services of a number of specialists trained in different disciplines.

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Missions for Manned Military Spacecraft[1]

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In an attempt to provide a framework for the systematic development of crew stations for the military spacecraft of the next decade, the operational and supporting military objectives which might be assigned to such vehicles und the human and technological resources anticipated for the era in question are subjected to analysis. Six elements of space travel are distinguished, and three concrete missions are synthesized of the six elements. It is concluded that it would be a conservative decision to focus the crew station development effort on the needs of an earth-orbit ferry.

It has been our purpose in this article to provide a basis for planning the crew station development effort for the military spacecraft of the next decade. This effort will be predicated on assumptions regarding the missions of the vehicle systems for which it is undertaken. We believe that realistic assumptions can be arrived at through a study of the military objectives and the human and technological resources anticipated for the era in question. We have, therefore, analyzed those objectives and resources in a general way. On the basis of our analysis we have defined three possible missions in relation to which we could consider the objectives more concretely. And, finally, we have drawn some conclusions as to the profiles of likely and worthwhile military missions for which spacecraft and their crew stations may be developed.

OPERATIONAL OBJECTIVES

Numerous military objectives have been proposed for manned vehicles operating outside the earth's atmosphere. Although some of these are of dubious feasibility (e.g., missile bombardment of the earth), the picture we have tried to present is inclusive rather than narrowly critical.

[1] This article is based upon a technical report[1] prepared for the United States Air Force under Contract No. AF33(616)-5901, monitored by the Flight Control Laboratory of Wright Air Development Center. Permission is granted for reproduction, publication, use and disposal, in whole or in part, by and for the United States government.

Operational objectives fall naturally under the broad headings of force and intelligence, corresponding to the system functions of transmission and reception. Considering a military establishment as a single system, its input is intelligence and its output is force.

Force

The force need not be applied to be effective, however. For many purposes force withheld may be of equal or even greater consequence than force applied. But only force which can be applied can be meaningfully said to be withheld. Therefore, we shall consider the varieties of applied force, bearing in mind that for each the threat of application may better serve an end than the fact. There are two ways in which military force can be applied by a spacecraft: the vehicle can serve as a weapons platform, and it can provide tactical transport.

An appreciation of the potential of a spacecraft as a platform for weapons may be gained by considering the type of weapon to be carried and the type of target to be attacked. The weapons might be missiles. They might carry nuclear or thermonuclear warheads. High explosive warheads are less likely. Or they might be the means of delivering chemical, radiological, or biological agents. Alternatives to missile weapons include various types of radiant transmitters. Propaganda broadcasts, both radio and television, are possibilities. Electronic countermeasures might be mounted from space. Transmission of beams of destructive energy ("death rays") cannot be ruled out of consideration.[38]

Strategic and tactical targets on the earth's surface would include industrial and military installations, population aggregates, and transient concentrations of hostile forces. Land, sea, and air masses might be attacked in order to affect weather, produce secondary radioactivity in the atmosphere, or interdict areas of potential military importance. But not all potential targets are planet-bound. A spacecraft's weapons may also be turned on other spacecraft and on long-range surface-to-surface missiles. Besides missile and radiant weapons, such targets as these would be vulnerable to orbital mine fields and even to swarms of inert particles, whose relative kinetic energy would render them as destructive as high explosive.

The spacecraft might serve to transport tactical forces to points at which they could threaten or apply military force. The targets of such force would include many of those mentioned above. The tactical forces which could be transported in this manner would include all types which might be deployed on the surface or in the atmosphere. The rapid movement of infantry, armor, and tactical air forces to the vicinity of their targets would secure the advantages of surprise and would maximize the shock effect of relatively small units. Tactical transport appears to lend itself particularly to police action, since the ubiquitous threat of their commitment would effectively multiply the strength of the forces involved.

Intelligence

Three different kinds of intelligence operations may be carried out by a military power—reconnaissance of physical conditions, surveillance of industrial and technological resources, and military surveillance. Each of them has as its objective the reception of a class of inputs to the military system of that power.

The physical conditions under which combat may be joined have always been a primary object of military intelligence. Historically the greatest interest has centered in features of terrain. In modern times meteorological and oceanographic variables have assumed increased prominence. And with the advent of the space age the physical and chemical characteristics of the upper atmosphere, the extent and character of fields of force in terrestrial and outer space, and the "geography" and "geology" of the moon and other celestial bodies have acquired military significance.

To a great extent the war-making potential of a nation is coterminous with the degree of its technological and industrial advancement. With so much of the great powers' technology addressed to military purposes, it is necessary to evaluate the effect of every advance in its industrial capacity and technological know-how upon a nation's war-making capability.

Military surveillance is concerned with the intentions and war-making capabilities of the military powers. The aggressor nation enjoys two significant and potentially decisive advantages: initiative and surprise. With the advent of hypersonic speed the advantages of initiative have become less than those of surprise. By denying the aggressor the possibility of surprise, it is possible to make his gamble on initiative unacceptably risky. To the nonaggressor who does not intend to exploit surprise, suitable positioning of space vehicles offers both intelligence of enemy intentions (i.e., it denies the enemy the certainty of surprise) and a proximity for counteraction that establishes an ever-present initiative potential from which to "wage the peace."[25] A power may also exercise surveillance of its own forces to provide rapid feedback of its actions on a global scale.

SUPPORTING OBJECTIVES

Supporting military objectives are those which are sought for their facilitating effect on the achievement of operational objectives. They include research and development fundamental to the military art, training and indoctrination of personnel, aid to navigation, both terrestrial and extraterrestrial, provision for remote guidance of vehicles, establishment of long-range communications systems, and the logistical support of all elements of the military establishment. A single mission may, of course, have multiple objectives, both operational and supporting.

Research and Development

Manned spacecraft will offer a breathtaking scope of usefulness in military research and development. In general we may divide their uses into two categories: those dealing with technological development and those dealing with more fundamental research.

Laboratories and testing facilities in space can be expected to play a role in the engineering development of the devices and techniques of space warfare. For example, an extraterrestrial testing ground for thermonuclear weapons may well be essential for the further development of such weapons. But even more important in the long run is the general requirement for testing a device in its proposed operational environment.

It is difficult to imagine any branch of science which could not in some way be fundamental to military technology. And many branches of science will be able to exploit the laboratory of space. The hard vacuum and freedom from external force offer experimental opportunities heretofore unavailable. Biological, psychological, and medical studies can be expected to flourish[19] and to pave the way for man to live safely and sanely in space. Astronomers will penetrate the atmospheric murk, and meteorology and the geosciences can achieve revolutionary advances.[19] We live on the earth, but it will only be when we can stand off and view it from afar that we shall learn many of the things we wish to know about it.[1]

Training

As our technological capability for space operations increases our need for trained personnel will likewise increase. Classroom, simulator, and flight training on the earth and in the atmosphere will be of great value. Even so, there are environmental conditions in space that cannot be simulated on the earth. Therefore, actual experience beyond the atmosphere is essential to qualify personnel to participate in space operations. Large numbers of such personnel would be needed in case of a war fought in and from space.

Navigation and Guidance

Both terrestrial and extraterrestrial vehicles have a requirement for navigation and guidance information. An orbital beacon whose position is tabled in an ephemeris would provide exact positional information to terrestrial navigators. Astronavigators could just as well calculate their positions from the celestial bodies, but if the beacon transmitted a pulsed signal of known frequency they could calculate their radial velocity.[28] Finally, an orbital beacon could transmit a command signal for the guidance of missiles or other vehicles.

Communications

The strength and quality of radio and television signals would be greatly improved by an orbital relay station which could maintain a line-of-sight link with both transmitter and receiver.[1] Satellites could perform this function either as passive (reflecting) or active (relay) transponders.[8] Three such stations in a 24-hour orbit, as suggested by Clarke[13] and others, would serve the world. Similar stations, suitably placed, could relay between other points in space, thereby providing a valuable service in the transmission of military information over great distances in a short time.[32] This objective, as well as those presented in the preceding section, could be achieved by unmanned satellites. There is no reason, however, why they should not be assigned as secondary objectives to manned vehicles.

Logistical Support

In the near future the manned spacecraft, with its high fuel consumption, is likely to create more logistical problems than it solves. The antipodal rocket does offer promise of economical transport at very high speeds (less than 30 minutes from take-off to touchdown).[1] Later on it may be found more economical to supply certain kinds of material from extraterrestrial sources than to boost it through the earth's gravitational field.[13] But for the period under consideration the ferrying of supplies from earth to orbit is liable to be a salient aspect of space travel. The supplies may well be accumulated in orbital dumps, from which manned spacecraft can take them on as needed.[12]

HUMAN RESOURCES

In planning manned systems to carry out particular military missions in space we draw on two kinds of resources: human and technological. These must be considered separately, since human capabilities are relatively constant, fixed by a human nature which evolves at the slow pace of natural selection, while the state of technology advances at an ever accelerated rate. The system planner is faced with such questions as "What can men do in support of the system?" "What can be done better by the residual system?" and "How can the control of the system be allocated so as to take the fullest possible advantage of both human and technological resources?" The allocation of functions between crew members and the residual system defines the tasks to be performed by the crew.

The task[2] to be performed at any crew station consists of the relation which the crew member is required to maintain between the stimuli which can be received and the responses which can be transmitted at that crew station. Whatever the basis for an allocation, and however a task may be defined, it always consists of four elements: sensing or reading, interpreting, planning, and manipulating. The performance of the task depends upon the performance of each of these generalized task elements. However, for certain purposes one may choose to regard the demands of one or more elements of a given task as negligible. The remaining elements are then said to dominate the task, to be the primary residence of its difficulty. Indeed, the difficulty of the task is sometimes interpreted as the difficulty of its dominant elements. The human resources upon which the system planner relies in his allocation of functions are the abilities of men to overcome this difficulty, to meet the demands imposed upon them by the elements of which their assigned tasks are compounded. In considering the nature of those demands, the reader should bear in mind the disintegrating effects of free-fall,[21,31,36] altered work-rest cycle,[34] social isolation,[37] the "breakaway" phenomenon,[11,22] fatigue,[22] close confinement,[5,23,24,37] etc., on human efficiency.

[2] Our treatment of the crew members' tasks is based upon an unpublished analysis by the senior author. The present application of that analysis is pragmatically justified to the degree that it has produced a useful organization of the matters discussed.

Sensing or Reading

Since a task is the required relation between stimulus and response, the sensing or detection of the stimulus is clearly essential to the task's performance. The crew member must attend to the stimulus, and he must resolve it, or discriminate it from alternative stimuli. Vigilance and acuity are the demands imposed by this task element.

A task may involve two kinds of stimuli: conditions which are important in themselves (system inputs), and artificial indications of such conditions. The latter class of stimuli are called *display indications,* and the channels over which they are transmitted to the crew member are called *indicator displays.* Display indications may be for any sense modality — i.e., they may be visual, auditory, tactual, vibratory, etc. System inputs which are indicated to the operator in this fashion are sensed by the residual system.

But components of the system's sensing function may also be allocated to the crew. The three main types of input which a man can sense are light, sound, and external forces. Visual observation of the earth and celestial bodies, as well as of other spacecraft, may well prove difficult. Rapid changes of brightness levels, great contrasts between light and dark areas, and a painful glare can be expected if direct vision into space is practiced. Fatigue and difficulty in seeing could be expected if the crew members were required to search visually the space outside their vehicle for a very long period of time.[10,40] Acoustic inputs will likely be of little consequence, since beyond the atmosphere they can only originate within the vehicle itself. And when an external force (viz., propulsion) must be sensed, the requirements for accuracy can scarcely be met by the most sensitive of instruments. Moreover, the sensed force must be accurately integrated if its sensing is to be useful. It appears, then, that man's employment as a sensor will be limited to the visual modality, and that it will not be extensive even there.

When the stimulus which a crew member senses in the performance of his task is a display indication the sensing process is termed *reading*. The acuity and vigilance demanded by reading can be minimized through sound display design. For example, it may be possible to offset a loss of vigilance by the redundant use of display indications for two modalities. Thus a change in the indication in a visual display may be brought to the attention of a crew member by a supplementary auditory indication.[22] If the stimulus to be sensed is important in itself the more general term, *sensing*, is used. Since the demands of input sensing can seldom be affected by design engineering, there are many input components for which it is not feasible to allocate this function to the crew member. For the sensing of inputs beyond man's capability, instruments must be provided.

Interpreting

In order to realize the required relation between stimulus and response, the crew member must not merely sense inputs and read display indications — he must interpret[3] them. His response, or *interpretant*, must have two aspects: it must reflect the state of the system — i.e., its instantaneous output vector — and the state of the system's environment. For any given mission the environmental input has an image on the output vector. This image is the required output. The crew member must interpret the stimuli which he receives as signs of the system's output in relation to its required output.

The interpreting process consists of the intercorrelation of past and present components of the stimulus vector. The trend of a stimulus component may be determined by the comparison of its successive values. Different components of the stimulus vector or their temporal patterns may be intercorrelated. Or the total complex as it changes in time may be discriminated and serve to mediate the crew member's response to the designated conditions.

The successful interpreting of the stimulus vector depends upon the existence of certain conditions in the interpreter. These conditions interact with the stimulus in the interpreting process. Chief among them are the conditions which govern, or program, the interaction of components of the stimulus with each other and with traces of past stimuli. These conditions are the persistent traces of the interpreter's training and indoctrination. They may refer directly to the relation between stimulus and required response, or they may refer to that relation indirectly via the *designatum* of the stimulus and the effect on the system's output which any given response would achieve.

The demands imposed by this task element, then, are the capacity to store the interpreting program on a long-term basis and the short-term storage capacity necessary to carry out the program. Special training will be necessary to establish interpreting programs adequate to the exotic environment of an orbital vehicle.[15] For example, a crew member peering through a porthole will be confronted (if he is not blinded by the direct or reflected rays of the sun) with a field containing no detail upon which he can accurately focus. The resulting "empty field myopia" will impair his judgment of size, distance, and speed.[10,40] Again, there is reason to expect that the absence of external force in free fall will prove confusing to the inexperienced spaceman.[21,31,36]

Planning

We have already indicated that the crew member's response must reflect the actual and required outputs of the system. Specifically, it must be the first of a projected series of responses which, if carried out, would result in the convergence of actual and required output. The construction of such a series constitutes the planning process. In this sequence the instrumental character of the responses as means to the adjustment of the system's output is analogous to the semantic character of the stimuli as signs in the interpreting process. Indeed, planning may be conceived as the mirror image of interpreting. In interpreting, stimulus components distributed over negative (past) values of time are intercorrelated. In planning, the process is reversed

[3] Our treatment of the semiotic aspects of stimuli is based upon the work of Charles W. Morris.[30]

and response components are projected onto positive (future) values of time.

An illustration may clarify the matter. Let us suppose that two points (the stimulus) on a road map are interpreted as signs of the interpreter's actual and required positions. Now, as planner, he must construct a route between them. That is, he must project a series of choices which, if carried out, would result in the convergence of his actual and required positions. The result of the planning process, then, is a judgment as to the means of achieving an end.

In the illustration, the planning process is seen to be an operation upon the results of the interpreting process, the interpreted stimulus. Its success depends upon the existence of certain conditions in the planner, including chiefly, as in the case of interpreting, traces of the planner's training and indoctrination. Planning consists of an interaction of the components of the interpreted stimulus and of projected responses. It is successful to the degree that it is governed by the program laid down in previous experience. That program may vary in explicitness, of course, from an exact prescription of stimulus-response relations to a general account of the principles of operation of the system and the goals to be achieved by it.

The demands of planning are not in general different from those of interpreting, although in detail they may be quite dissimilar. The planner must be able to store programs for constructing instrumental sequences of projected responses, and he must be able to store the elements of those sequences during the process. As in the case of interpreting, special training will be needed to establish the desired planning program. The inadequacy of normal habit patterns for an environment lacking any frictional damping of mechanical reaction has been demonstrated in experiments at WADC's Aero Medical Laboratory.[14]

Manipulating

The final element of a task consists of the translation into action of the first projected response of the planned series. This task element may be conceived as the mirror image of sensing. Its demands, corresponding to vigilance and acuity, are muscular coordination and muscular strength.

The term *manipulating* is employed in an extended sense to denote all types of effector activity, including actions not involving the crew member's hands at all, such as pedal activation and speech. Two types of response may be required of a crew member. Control actions, which correspond to display indications, are signals to the residual system. Over purposely provided channels — viz., the controls — they communicate to the residual system the crew member's interpretation and judgment of the stimulus. Ordinarily it would only be through his control actions that he would attempt to adjust the system's output. But the possibility exists, particularly under emergency conditions, of improvised responses not supported by controls. That the ability to move the body and its parts as desired in free fall rapidly improves with practice has been demonstrated by experiments at Wright Air Development Center in which human subjects were left unrestrained in the hold of a C-131 aircraft during zero-lift flight.[7] The demands imposed by this task element may be minimized by sound design of controls, at least insofar as the required response is a control action.

TECHNOLOGICAL RESOURCES

Among the demands made upon technology in the development of a man-spacecraft system perhaps the most obvious is for a vehicle. The structural requirements vary widely with the system's mission, depending, for example, upon whether the vehicle must sustain great external forces or whether it is to operate in an atmosphere or exclusively in vacuum.[12] A source of energy is also essential. Chemical reactions, compressed gases, the sun, nuclear fission, and nuclear fusion may find application aboard these vehicles in the decade 1960-70.[3] During this period the chemical rocket engine appears to be the most feasible means of propulsion, owing to the testing and experience on missiles and satellites gained in the late 1950's and early 1960's.

Late in the decade light-gas rockets and ion rockets may become available for operations in deep space.[27] But only through chemical rockets will it be possible to boost a human payload into orbit.[18]

Other technological resources will aid the crew members in their control of the system. Their abilities to sense the system's input will be supplemented by an advanced and expanding art of detection. Instruments may be provided to inform them of the direction, range, and radial velocity of environmental objects; of the attitude and angular velocity of the vehicle; and of the magnitude and direction of a resultant external force on the vehicle. Automatic digital computers will be available to assist them in navigation and guidance. It seems possible that these computers will be located at earth bases and connected into the vehicle system by radio link.[13]

Protection Against Environmental Hazards

A sealed pressurized cabin will protect the crew against the outer vacuum, but crew members can be expected to wear pressure suits (in the unpressurized condition) until the reliability of the pressurization system has been completely proven. Compartmentation of the vehicle may be used to insure their safety further.[29]

Tolerance for external forces resulting in accelerations greater than 1 g can be increased to a safe level through proper positioning of crew members,[6] possibly supplemented by the use of suitable pressure garments. We are less certain about the problems of reduced external force, including those associated with the completely force-free state. It has been possible, however, to study the effects of apparent weightlessness for short periods in aircraft flying Keplerian, or zero-lift, trajectories.[7,31] As far as the authors are aware, neither these studies, nor studies made of monkeys in rockets, nor the Russian experiment in which a dog was placed in orbit, indicate any insuperable difficulty.

Results from the artificial satellites indicate no temperature extremes against which crew and equipment cannot be protected by double-hull construction, vehicular rotation, and a good air conditioning system.[16] The outer hull will also serve as a defense against the sandblasting effect of cosmic dust.[39] The probability of encountering a meteoroid large enough to cause a disaster seems quite small.[39]

Cosmic radiation may be the one factor which limits man in his ventures beyond the atmosphere. Adequate shielding may prove too massive to lift into orbit by techniques available before 1970.[35] New developments in shielding and propulsion may eliminate this problem. However, such advances should not be relied upon as early as the next decade.

Solar radiation may prove to be a serious inconvenience. It will not constitute an insurmountable barrier, however, since it can easily be excluded from the cabin by relatively thin layers of protective material and, over the transparent areas, optical filters.[9] Irradiation of the cabin by a nuclear power plant must also be prevented. Proper positioning of the cabin in relation to the power plant, plus a little shielding, should prove sufficient.[13]

Ecological Support of Crew

Besides affording its crew protection against the hazards of space travel, the vehicle will have to provide for certain interactions between the crew members and their artificial environment. The latter must interact with the crew members much as their normal mundane environment would if their life processes are to continue successfully. Generally speaking, two classes of such ecological interactions may be distinguished: metabolic and psychological. The former class includes the exchange of materials, such as food, water, oxygen, and bodily wastes, between crew members and the vehicle. The latter class subsumes such interactions as stimulation and exercise.[3]

In the next decade we can expect the strategy of metabolic ecology to be one of storage and jettison, in contrast to a more radical and sophisticated ecosystem. Canned food, oxygen tanks, chemical or physical carbon dioxide and water vapor removers, and chemical waste disposers or jettison techniques would meet essential biological requirements for short-term voyages.[17,26] The closed cabin at Randolph AFB,

Texas in which a man resided for a week was so equipped.[17] Provision for the recycling of water and oxygen is a possibility for the more extended missions.[26]

SELECTED MISSIONS

Elsewhere[3] we have distinguished three phases into which all space travel may be divided: ascent from the world of origin, operations in deep space, and descent to the world of destination (which may also be the world of origin). It is not necessary for any particular passage through space to involve all three phases. However, the phases are exhaustive and embrace all forms of space travel which have been seriously considered.

Each of the three phases lends itself to a further dichotomy. Since the worlds of origin and destination may or may not be gas-enveloped, ascent and descent can occur either in vacuum or in atmosphere. And deep-space operations can be carried out either in an orbit which is closed about a primary or in an open path such as a hyperbola. Thus we arrive at six elements of which to compound a spacecraft's mission. Like the phases, these elements are exhaustive. Therefore any mission can be exhaustively described (at this level of generality) as a sequence of mission elements. We call such descriptions *missile profiles.*

Just as the organic chemist assembles complex molecules from the atoms of only a few chemical elements, so is it possible to compound of these six elements of space travel missions of any complexity. Each column of the table is the profile of one mission. The elements named at the left occur in the order indicated by the numbers in the column.

These profiles were selected to illustrate the combinatorial possibilities. They range in complexity from *e*, which might represent the mission of a satellite constructed in orbit, to *h*. The latter profile might be interpreted thus:

1. Ascent from the earth
2. Orbit about the earth
3. Open path to the moon
4. Orbit about the moon
5. Descent to surface of the moon
6. Ascent from the moon
7. Orbit about the moon
8. Open path to the earth
9. Orbit about the earth
10. Descent to surface of the earth

The artificial satellites in our skies have realized profile *a*. A successful moon shot might be described by *b*, and a circumlunar satellite by *c*. Profile *d* could represent the mission of a manned earth satellite or of an aerodynamic ferry. The mission of a pure transfer vehicle would have profile *f*. Mission profile *g* belongs to a ferry operating between the moon's surface and a circumlunar orbit. The possibilities of extending the table are obvious.

The special capabilities which a spacecraft system must have in order to achieve its assigned objectives are largely dependent upon the elements which compose its mission. We have discussed this dependence more fully in another place.[4] The objectives of space travel, however, are properly considered in relation to concrete missions. We have therefore selected for further

TABLE 1

Some Illustrative Mission Profiles

	a	b	c	d	e	f	g	h
Ascent in atmosphere	1	1	1	1				1
Ascent in vacuum							1	6
Closed orbit	2		3	2	1	1,3	2	2,4,7,9
Open path		2	2			2		3,8
Descent in atmosphere				3				10
Descent in vacuum		3					3	5

study the missions of an earth-orbit ferry, an experimental space station, and an earth-moon transfer vehicle.

These missions have profiles *d*, *e*, and *f*, respectively. We believe that in the next decade these will be the profiles of most general applicability[4].

They afford a broad sampling of special-purpose spacecraft. And the particular missions which we have chosen from the classes defined by the three profiles form an interdependent set. The experimental space station and the earth-moon transfer vehicle both presume a successful ferry, and by assigning the ferrying mission to a special-purpose vehicle it is possible to secure the advantages of specialization in the remaining vehicles.

Mission For An Earth-Orbit Ferry

This vehicle ascends from the earth, makes rendezvous with an orbiting deep-space vehicle, and returns to earth. Thus, its mission is characterized by profile *d*. The primary mission objective is the logistical support of the orbital station.

The mission is of short duration (on the order of ten hours), since the time for ascent, transfer of cargo, and descent is small. Since most of the space aboard is occupied by cargo, and since the energy requirements for the mission are large, the crew is limited to one or two men. On these missions, when space is available, other personnel can be included for orientation and training purposes.

As a secondary objective of the mission, the gathering and reporting of such physical data (temperature, dew-point, fields of force, etc.) as may be obtained along the trajectory of the vehicle would provide valuable information to ground-based installations.

The earth-orbit ferry might well be used for testing and refinement of equipment, systems, and techniques. The length of the voyage is short, and the capability for rescue would be greater than if the equipment were tested in cislunar or more distant space. Of course, the equipment would be sufficiently perfected to provide the crew with maximum protection. Guidance systems, ecological systems, experimental primary and secondary energy sources, improved structural design, etc., are examples of things which might be tested operationally on these ferries.

Still another secondary objective of the mission might be training. Certainly the capability of giving military personnel exposure to actual space conditions will be limited by the cost and risk involved. By using these short-duration trips as training missions, a large number of men could be trained in space operations.

The logistical support of an orbital station may include transportation of supplies: foods, liquids, oxygen, medications, clothing, toiletries, mail, propellant, repair parts, replacement parts, equipment modification kits, additional equipment, photographic materials, personal items, etc. Also included in logistical support is the transportation of personnel: replacement, additional, sick and injured, specialized equipment repair, installation, medical, scientific, etc. The flow of personnel and supplies is two-way — i.e., from earth to orbital vehicle and from orbital vehicle to earth.

The cargo (both materiel and human) is loaded and secured prior to the launch. The launch time, direction, and velocity must be quite accurate to permit the ferry to rendezvous with the orbital vehicle. This is because of the large amounts of energy required to achieve changes in orbit.

If the ferry is launched so as to enter orbit close to the orbital vehicle, then rendezvous to effect cargo delivery should not be difficult. It can be expected that the orbital vehicle will transmit a signal which equipment aboard the

[4] Consider, for example, the earth-orbit ferry. We describe it in terms of the requirements to achieve logistical support of a space station. Instead of this mission, the vehicle which has the ferry's profile might be assigned the primary objective of reconnaissance from orbit, with a secondary objective of electronic countermeasures. Indeed, this may be the more likely mission. A close-in orbit of short duration is the only way known at this writing for giving the crew effective protection against the recently discovered radiation belt to be found at altitudes above 400 kilometers. Unless other means of protection can be developed, the manned deep-space vehicle may never be realized, and the need for a ferry may never arise.

ferry can receive and interpret in terms of direction and distance to the vehicle. Since the velocities of both the deep-space vehicle and the ferry are determinable, a cut-off vector to intercept the former can be readily computed. This function could be allocated either to the crew or to the equipment. Equipment might better be given this function since it would be quicker with less chance for error. The decision when to initiate closing could be allocated to the crew, as could the control of the direction and magnitude of the thrust vector. Thrust vector control could also be allocated to the equipment, but since the distance and direction of the orbital vehicle as well as the optimum intercept course can be indicated to a crew member he might as well have the power of decision. As he approaches join-up, he can take over visually. This operation should not be more difficult than mid-air refueling as we know it today.

Upon join-up, the vehicles can be attached to each other to permit the transfer of cargo. This could be direct or by a pod released from the ferry and attached to the other vehicle.

After completion of transfer, the ferry must continue in orbit until a point is reached which will permit descent to the landing area of choice. The decision to initiate descent should be given to a crew member so that he can choose the touchdown area. The computation of the point in orbit at which to initiate descent might be allocated either to the man or to equipment. As in the computation of the cut-off vector, the machine could do it quicker and with less chance of error.

Mission For An Experimental Space Station

As the prototype of a manned reconnaissance satellite, this vehicle has the primary objective of military technological development. A deep-space vehicle constructed in orbit, its mission profile would be of type *e*. The entire operating life of the vehicle would be spent in a closed orbit about the earth. Its occupants would be rotated and supplies furnished by means of an earth-orbit ferry. One ferry trip every three days should keep the vehicle adequately furnished with supplies and rotated personnel.[1] However, due to the great expense and danger of getting a vehicle out of and back into the atmosphere during the 1960's, the tour of duty and replenishment of supplies may be between twelve and twenty-five days. Habitability could conceivably be maintained on a Spartan basis for a month at a time.[1] This assumes some reclamation of used materials, but essentially the problem demands nothing new for solution. The length of this period, as well as the various functions to be allocated to the crew (e.g., watch keeping) dictates that at least three men be included. In the course of time it may be expected that the original satellite will grow by gradual accretion from outhouse to perhaps metropolitan dimensions, enabling the scientific specialist to replace the pioneer jack-of-all-trades. Astronomers, photographers, psychologists, physiologists, engineers, physicists, chemists, etc., would all have their role to play.

The surveillance of the industrial and technological development of the enemy is the primary military objective of the spacecraft whose prototype the experimental space station is. It can be expected that valuable intelligence will be obtained as a by-product of the development of surveillance techniques. Construction and expansion of industrial complexes and transportation facilities, changes in the pattern of activity, mining operations, hydro-electric developments, nuclear power plant construction, nuclear and thermonuclear weapons testing, and the testing of rockets — all such developments can be pinpointed as they occur by optical, infra-red, and scintillation detection devices. Additionally, observation from the satellite would greatly facilitate such ordinary activities as iceberg patrol, traffic study, aerial mapping, and any number of other observational tasks to which great altitudes lend themselves.[1] Cartographic studies of the earth's surface from the orbital vantage point will reduce mapping errors from a current standard of ½ to ¾ mile to thirty feet throughout the world.[2] This 99% reduction of error would be reflected in the practice of intercontinental ballistic bombardment.

To a great extent this kind of surveillance

could be carried out by an unmanned satellite and probably will be within a short time. Observations can be recorded photographically, or electrically encoded and stored on tape, to be released in a pulse upon remote interrogation. Additional flexibility can be obtained by employing a human observer. Observations can frequently be interpreted immediately without having to pass through an intelligence processing center. A human observer is capable of noticing the unexpected, unlike a machine which merely carries out a relatively simple program. And a man can immediately search for confirmation of an unexpected observation, without having to wait for instructions from the ground.

Just as unmanned orbiters are gathering data permitting the establishment of the initial manned satellites, so will the initial manned satellites have the primary objective of developing and testing techniques and devices for the more permanent space stations. Living and recreation arrangements, work-rest cycles, observational procedures, power generation, maintenance and repair techniques, pressurization requirements, equipment, and the like would be investigated so that permanent satellites could be made self-sustaining from the habitability-energy-sanity standpoint. Other objectives which might be assigned to this vehicle include the development and testing of hydrogen bombs, weapons to be launched from space to earth, electronic countermeasures, and weapons to be launched at other space vehicles. Development of greatly improved terrestrial and interplanetary communications and navigation systems would be an aspect of the space station's work.

The space station might be employed as a laboratory for the investigation of such physical conditions as vacuum, radiation, free fall, the distribution of geomagnetic lines of force, and variations in the earth's gravitational field.

It could readily be equipped as an astronomical observatory. Radio telescopes of fantastic size could be assembled in the force-free state — huge fragile instruments which would collapse under their own weight on earth.[1] There are no doubt important problems to be overcome in the erection and use of such apparatus, but their value to science need only be mentioned to justify the effort.

Equipped for biological and psychological research, the space station will allow us to confirm the necessarily crude observations previously made, and to carry out further studies basic to man's safe, sane, and efficient habitation of space. Among the questions awaiting answer are: How will prolonged exposure to the force-free state affect a man's behavior? How will this treatment interact with close confinement in the constant company of a few other men? What will be the long-term effects of the force-free state on single-celled organisms normally in symbiosis or conflict with man? Research on these and many other important questions is scarcely possible under the crippling hand of the earth's gravitational field.

High resolution optical and infra-red reconnaissance gear will make possible the study of the generation, growth, and course of hurricanes and tornadoes. Investigations of the earth's long-term balance between incident and emitted radiation, climatic changes, solar phenomena, and tropospheric weather can be correlated in an effort to learn the mechanism by which weather and climate are externally controlled.[33] Man's own control of the weather might ensue, with its clear military implications. Merely by filling in the gaps in cloud observations over the uninhabited land and ocean areas of the world a substantial gain is assured. At present, less than 5% of the earth's atmosphere is covered by meteorological observation.[20] The data so obtained could be relayed to planetary collating centers at which synoptic short-range day and night weather pictures could be maintained whose accuracy would be of inestimable value to industry and agriculture. And the military value of such data would be beyond economic reckoning.

The space station will offer on-the-job training for future spacemen, with the added feature of relatively close proximity to earth should something go amiss. The crewmen will experience living in close proximity to each other for weeks and perhaps months on end. They will

perfect their techniques of surveillance, research, maintenance, medical care, airlock entry and emergence, and safe personal maneuvering in space; develop greater skill at spacecraft control and practice techniques of astronavigation; accustom themselves to the force-free state; and in all likelihood practice their chess.

The advent of transfer vehicles will require the space station to assume additional responsibility for logistical support of lunar and interplanetary voyages. Receiving, storage, and transfer of supplies and equipment to the transfer vehicle would be involved in the fulfillment of this objective.

Mission For An Earth-Moon Transfer Vehicle

The chief military objective of this mission is reconnaissance of the moon's surface from a close-in orbit, with a view to the establishment of a base. Beginning and ending in a closed orbit, this mission belongs to the class characterized by profile *f*. The missions so characterized are not the only possible missions between worlds (Cf. profiles *b* and *c*), but they are likely to be by far the most efficient, securing as they do the advantages of specialized design.

For a journey of this duration a three-man crew would be desirable. The greater size required for a multiple-man vehicle would result in no more than a proportionate increase in cost, since it would be constructed in orbit. Never being exposed to any external force which would produce as much as one "g" of acceleration, its required structural strength would not rise as fast with increased size as on the earth.

A cartographic survey of the lunar surface could be carried out very easily by an orbiting spacecraft system. The absence of atmosphere would not only permit an orbit of negligible altitude, it would increase the resolution of observations from any altitude. At low altitudes, of course, the orbital velocity would be necessarily high. This is all to the good, as it permits more passes over the lunar landscape in a given time, each slightly precessed from the preceding one. Photography and visual scanning would be the primary techniques. Radar and explosive projectiles to sample the surface composition might be used. Only one-half of each revolution would be available for optical observation, of course.

The three-man crew will make possible the study of social phenomena under extended conditions of space travel, perhaps for the first time. Previous studies of biological and psychological effects of free-fall can be extended for longer time samples.

Man's first splashings in the sea of space will have occurred in the near vicinity of the earth. This mission offers an opportunity for him to discern and perfect his capability for longer voyages.

SUMMARY AND CONCLUSIONS

It has been our purpose to provide a framework for the systematic development of crew stations for the military spacecraft of the 1960's. To that end, we have analyzed in a general way the military objectives and the human and technological resources anticipated for the era in question. We were able to distinguish two kinds of operational objectives: force and intelligence; and five kinds of supporting objectives: research and development, training, navigation and guidance, communications, and logistical support. Human resources consist of the abilities of men to meet the demands of the four generalized task elements: sensing or reading, interpreting, planning, and manipulating. Technological resources include those upon which the system designer can draw in meeting the system's structural requirements and its requirements for energy, propulsion, automatic computation, input sensing, protection against environmental hazards, and ecological support of its crew. From this general analysis we proceeded to a consideration of missions.

We noted that the special requirements which a vehicle system must meet in order to achieve its assigned objectives are to a great extent determined by the elements of which its mission is compounded. Objectives, on the other hand, seemed to be more appropriately considered in relation to complete missions. We therefore defined three missions for which vehicle systems might be developed in the next decade or so:

one for an earth-orbit ferry, one for an experimental space station, and one for an earth-moon transfer vehicle. The seven kinds of objectives previously distinguished were considered for each of these missions. The primary objectives to be achieved in these three missions are not such as to provoke countermeasures on the part of the enemy. This is significant, since the cost of destroying a hostile vehicle would be minute in comparison with the cost of creating it and establishing it in orbit.

As we have noted, the missions of the experimental space station and of the earth-moon transfer vehicle would be dependent upon the third mission, that of the ferry. And of the three, the latter involves the briefest exposure to extraterrestrial radiation. In view of the present uncertainty about protective measures to be taken against radiation, it would be a conservative decision to focus the crew station development effort on the needs of the earth-orbit ferry. This is the vehicle for whose mission the prospects are brightest, and whose mission must succeed before either of the others can be undertaken. To be sure, there will be no need for a ferry in the absence of deep-space vehicles. But the profile of the ferry's mission is the same as the profile of a close-in orbital reconnaissance mission, and it is likely that the development of crew stations for the ferry would have value for other vehicles with the same mission profile.

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A New Concept: The Kinalog Display System

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A technique is described which may be used to resolve sensory conflict between visual and kinesthetic inputs. The forces acting on the operator's kinesthetic senses are shown visually and related to the attitude of the airplane and to the earth's surface for both individual cockpit instruments and an integrated pictorial display.

One of the causes of vertigo may be the conflict which a pilot encounters when he is faced with the problem of resolving the difference between the information he obtains from the visual displays and that which he receives directly from within his body. The anti-vertigo instrumentation described in this article is based upon the recognition that the pilot's body can not be redesigned nor can his internal feelings be eliminated. However, it might be possible to prevent the conflict by redesigning the visual displays so that these indicators would have the same adaptation which is characteristic of the human. This has been done and the new design is called the kinalog; that is, the instruments behave as a kinesthetic analog of the human body.

A pilot flying a kinaloged display does not have to disregard his feelings. What he sees agrees with what he feels, even during rapid maneuvers. Figure 1 shows a conventional attitude instrument for a banked turn to the right. The horizon is the only moving member of the display and it tilts to the left. This display assumes that the airplane's "up" on the instrument is the only useful reference.

In the past decade a great deal of interest has been evidenced in the question of which is better, to use the airplane (inside-out), or the outside world (outside-in) as a frame of reference. Figure 2 shows how the attitude display in a 45° banked turn would look as an outside-in display. The horizon is fixed and the observer sees the indication of the bank as though he were looking at the tail of his airplane from behind. Figure 3 shows the kinalog attitude presentation at the beginning of a 45° banked turn. The first thing a pilot feels is that the airplane has been tilted to the right. His body recognizes that the aircraft is truly the moving member. By the time he has reached the degree of bank he desires his body has already started to adapt, but at a rate much slower than the banking of the aircraft. This situation is shown in Figure 4. Note that the horizon has already started to tilt to the left. This reflects the beginning of his adaptation. The pilot maintains this bank, and as time proceeds, the display will appear as shown in Figure 5, and then as in Figure 6.

Human adaptation is essentially completed in 15 to 30 seconds, depending upon the amount of "g" force encountered.

Figure 6 shows the display as it would remain during the steady turn if this turn proceeded for any more than the adaptation time of the human body. To recover to level flight the pilot pushes the control stick to the left until the aircraft symbol becomes parallel to the horizon. The stick is returned to the central neutral position while the display proceeds through the adaptation as shown in Figures 7, 8 and 9. During this time the airplane is level as shown by the difference angle between the two moving symbols.

Prior to the kinalog concept it was generally considered that there were only two possibilities for displaying attitude, inside-out and outside-in, but it is clear that these two modes of display are really the extremes of a connecting continuum. At either extreme one of the two displayed referents (the aircraft or the horizon) are fixed, that is, the special case of zero velocity.

Right turn at 45° bank angle.

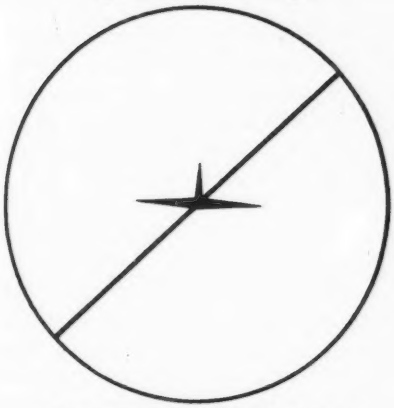

Fig 1. Inside-out attitude display.

Right turn at 45° bank angle.

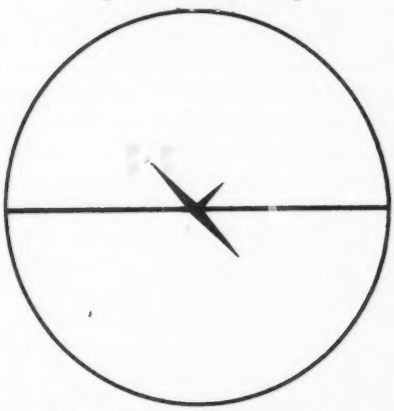

Fig 2. Outside-in attitude display.

During initiation of a 45° bank to the right for a coordinated turn.

Fig 3. Kinalog attitude display.

Just after reaching the 45° bank angle in coordinated right turn.

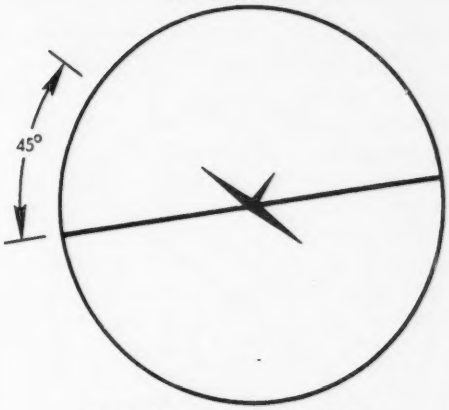

Fig 4. Kinalog attitude display.

Ten seconds after entry into steady 45° bank coordinated turn to the right.

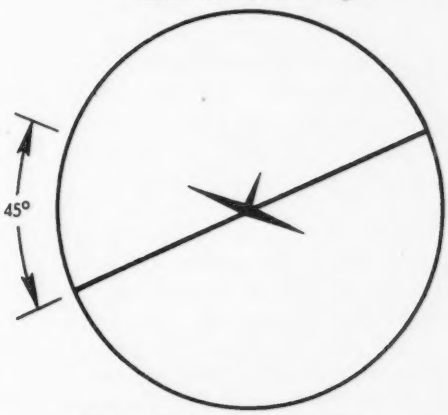

Fig 5. Kinalog attitude display.

Thirty seconds after entry into steady 45° bank coordinated turn to the right.

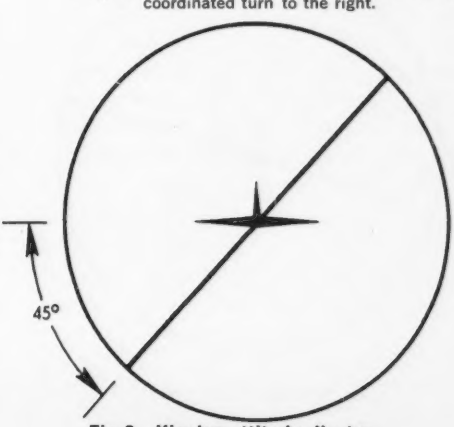

Fig 6. Kinalog attitude display.

Control stick to the left until aircraft symbol is parallel to the horizon symbol (aircraft is then in level flight). Neutralize control stick.

Fig 7. Kinalog attitude display.

Control stick remains in neutral center position while adaptation proceeds.

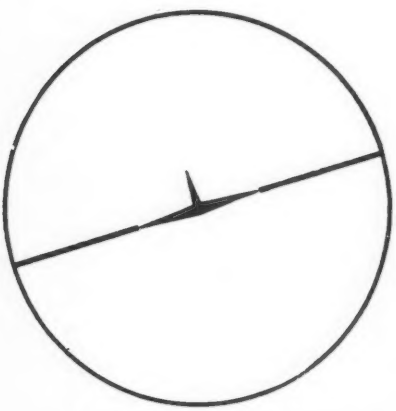

Fig 8. Kinalog attitude display.

Between the extremes these two modes are connected by allowing *both* members to move. Kinalog initially presents any maneuver almost as if it were an outside-in presentation, but then as time proceeds, it gradually changes until it finally becomes almost inside-out. The rate of this transition is determined by the continuously changing "g" force which is electromechanically sensed in the aircraft.

If the above illustrative example had involved a pitch change, then the same kind of adaptation to the new pitch would have taken place. After the nose rises to the new pitch both the aircraft symbol and the horizon gradually settle until finally the airplane moving member once again is in the neutral position. A sudden dive would appear as a drop in the airplane symbol to below the horizon bar. As adaptation takes place the two moving members gradually rise until the airplane again reaches the neutral position. A more complicated maneuver would have both members moving simultaneously. The important thing is that the instrument is alway telling the truth about the present attitude. This information is read from the difference between the two moving parts. Both members adapt together without changing the reading while they continue to maintain the pilot's knowledge of "up".

If a pilot makes a rapid sequence of maneuvers, the amount of adaptation to each portion of the maneuver is very small and the dynamic display appears to be a moving aircraft display.

In comparison, if he maintains a constant attitude and a slow drift develops, the display will reflect what he might not ordinarily be aware of. Here it would look predominantly inside-out.

Currently we stand on the threshhold of entry into space. Comparatively little is known about the effects of weightlessness. However, when manned rockets reach the near zero-g state, the human operator must still be depended upon to control his vehicle. Although separated from the earth, the human is not separated from his body. All his life he has depended upon his internal sensations. The new problems he will

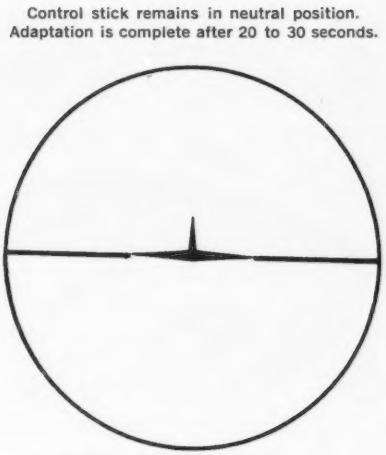

Fig 9. Kinalog attitude display.

encounter in space flight make it essential that he be presented with a compatible cockpit, one in which he can act almost intuitively with the confidence that his reflex responses will prove to be correct. The coming aero-spacecraft speeds will allow the pilot sufficient time to make only the most rapid decisions. To make correct decisions he must integrate a large amount of data. The cockpit design should therefore utilize all of the human information sensing channels including the kinesthetic.

The human factors engineering task to achieve the required integration is to design a cockpit which will provide only the necessary relevant data in the most meaningful manner to the pilot when he needs it. It is not enough to put all the numbers on the instrument panel. Each bit of information must be clearly associated with its meaning before it can be interpreted and digested, together with other related facts. One of the most efficient ways of compressing the data the pilot must perceive is to capitalize on the relationship between the different types of information. This is not a new idea of course. We already expect to find all the engine instruments grouped together, and all the flight control instruments arranged in like manner. But grouping is not enough. True integration can be accomplished only if one moving member portrays more than one of the quantities, depending on the pilot's viewpoint toward the display. For example, in a relaxed, clear weather situation, the flight control display is what the pilot sees through the windshield. Looking at the earth the pilot can estimate his altitude, pitch, bank, ground speed, present position or the relative distance to many points, all in the most natural, integrated display. "Most natural" is an important concept. It implies the method of integration which the pilot has lived with all his life. Real world relationships between the various quantities are maintained so that the pilot can immediately and effectively interpret the entire situation. This idea is the basis of application of kinalog in a new cockpit concept.

In the earth contact flying situation most of the pilot's attention is devoted to looking forward and slightly downward. Near the horizon he sees his attitude and below him he gets his position, velocity, and altitude data. Figure 10 shows this view and Figure 11 shows how the primary instrument will look on the new panel. Within a single display the pilot can read those things he ordinarily observes by looking through the windshield and, in addition he can obtain heading of the flight path, (from the vertical center line of the instrument), crab angle and heading of the aircraft (from the tilt of the triangle which represents his shadow on the ground), as well as any PPI radar information which can easily be superimposed on the display.

The modified pictorial window display shown utilizes a microfilm map of the earth which portrays only those features which the pilot may need.

Figure 12 shows a sketch of the mechanism for generating the display. It utilizes a light source which is projected through a modified pictorial microfilm map transparency. This is driven by the computed ground position and velocity taken from the TACAN or VOR-DME receiver. The light then passes through a fixed

reticle which has concentric circles indicating range from the present position and then through a prismatic distortion lens which is moved vertically by the pitch sensor and rotated according to bank angle. This lens gives the map perspective and places a curved horizon on the projected image. From here the light passes through a variable-magnification constant-focus lens system which is driven by the sensed pressure altitude. As the aircraft climbs, the magnification is decreased and the earth appears to drop away. In diving, the increase in magnification brings the earth toward the pilot. Separate transparencies superimpose the aircraft symbol for both attitude and shadow-position presentation.

It should be emphasized that the perspective picture which is seen by the pilot is not generated by a radar. Rather, it is the projection of a thin beam of light through a map transparency which covers the range of the aircraft and is carried within the instrument system. It is driven by the continuously computed ground position of the aircraft based upon its navigational electronics. The positional data may be extracted by the TACAN or VOR-DME receiver and this is used

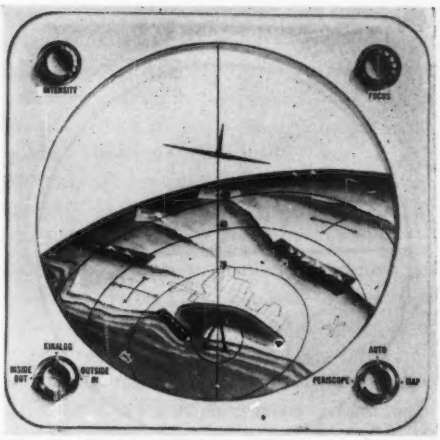

Fig 10. The modified pictorial window display.

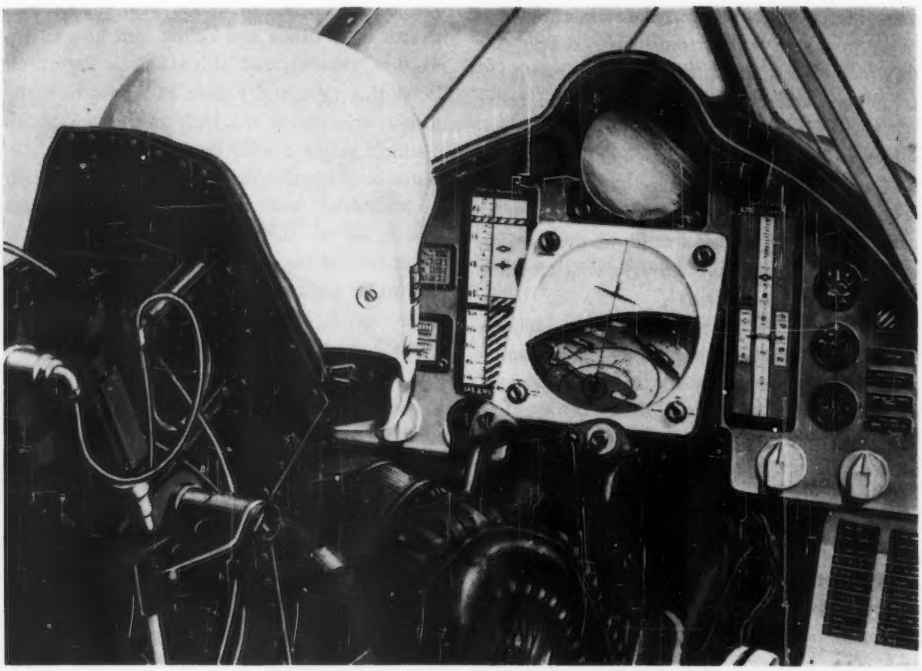

Fig 11. The conceived cockpit display panel.

to drive the transparency. A correct perspective is maintained by separately driving the prismatic distortion lens by the pitch and bank which are sensed within the aircraft. Together these separately derived sources of information combine to form a single composite view which accurately portrays what the pilot would see if he could see out of the aircraft.

The kinalog principle described can easily be incorporated into such a display. It is planned to put a three-position switch available on one flight test model which will allow rapid change from inside-out, to kinalog, to outside-in modes of display so comparisons can be tested. It is important to recognize that the kinalog principle and the integrated display are separate concepts. They can be used individually or combined without conflict. Some consideration has also been given to the possibility of incorporating an actual periscope which would allow the pilot to monitor the single display for both clear weather and IFR (Instrument Flight Regulation) flight. The switching could be done automatically. It would allow rapid transition from observation of the real world through the periscope, to monitoring the artificial map display, and back again to the real world; without interrupting the pilot's attention by either head movement or the refocusing of his eyes.

Initial evaluation of the described instrumen-

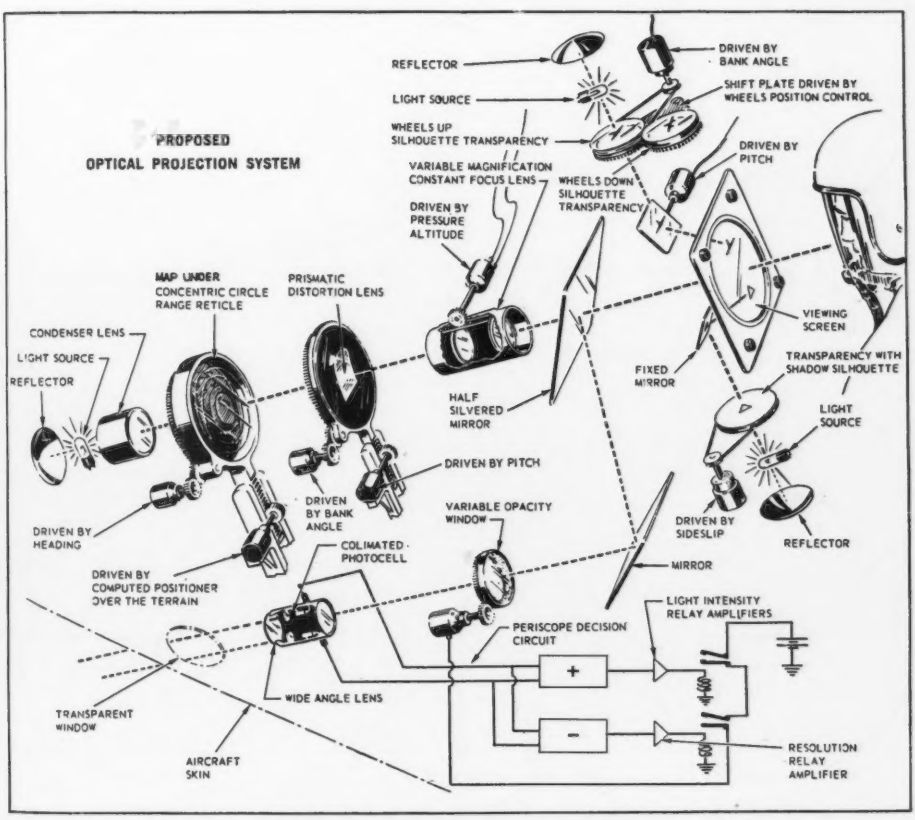

Fig 12. Proposed optical projection system.

tation was accomplished with the aid of a fixed ground simulator, and indicated the feasibility of the system. However, the simulator could not be used to evaluate the kinalog principle since such an experiment requires either a centrifuge or actual flight test.

The primary display described above presents most of the non-numeric information the pilot needs. It is planned to have auxiliary displays for use during precise maneuvers which might require numeric data.

As the human flies higher, the amount of unusual data he must utilize will continue to grow. It therefore becomes increasingly important to achieve a maximum of compatibility between the pilot and his cockpit.

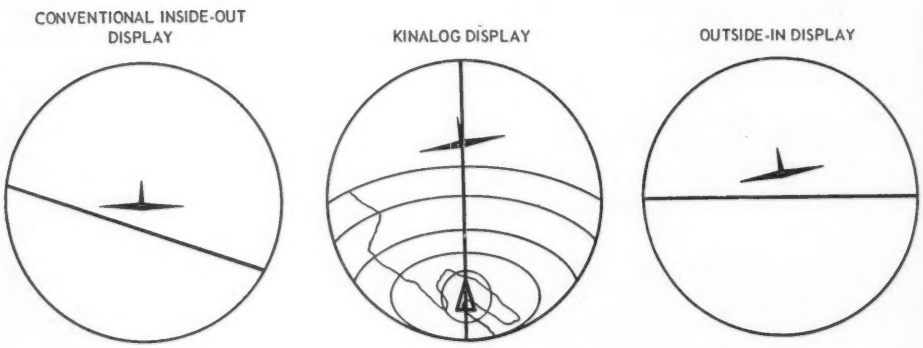

Fig 13. Suddenly induced climbing turn to the left. Control stick is pulled back and to the left.

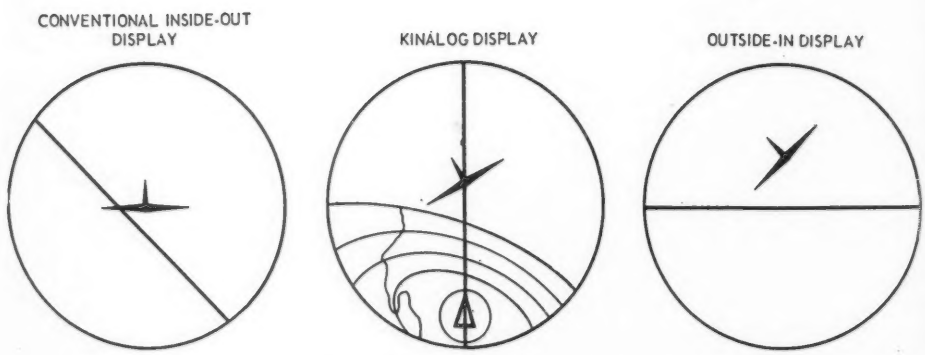

Fig 14. Control stick is neutralized. Aircraft continues to climb at the same pitch and bank angle.

Fig 15. Still climbing and turning several seconds later (after adaptation).

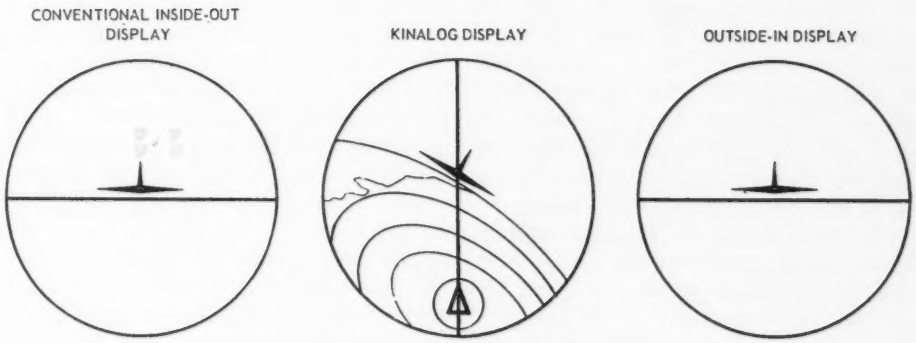

Fig 16. Just as level flight is attained.

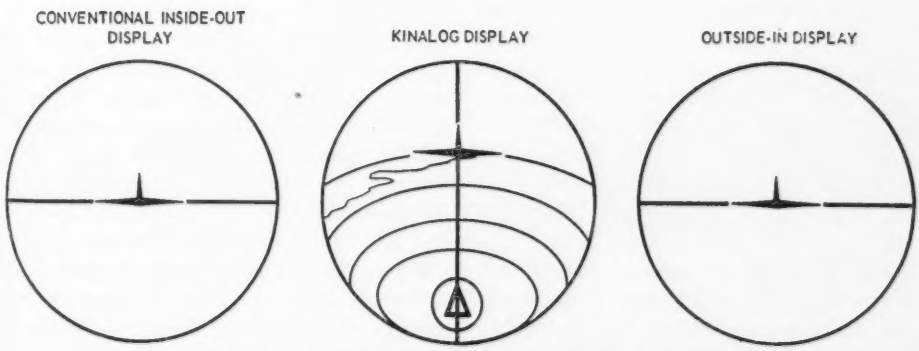

Fig 17. After adaptation of kinalog (and pilot) has completed.

Human Factors In Systems Reliability

GEORGE A. PETERS, Santa Monica, California, and **THOMAS A. HUSSMAN,** Psychological Research Associates, Inc., Encino, California.

A general introduction is made to the basic concepts involved in engineering for systems reliability. Attention is focused on the problems of performing human factors research which will be of maximum usefulness to those making engineering design and management decisions regarding the human element in systems reliability. It is urged that task variables be specified in quantitative units which are compatible with other engineering formulations and that there be greater emphasis on operational analysis under realistic environmental conditions. An idealized methodological approach to human factors research is also described.

The planning, design, and development of modern complex equipment systems is generally achieved by the process of breaking down the overall problem into its constituent parts, that is, by specifying the performance requirements of the several subsystems or component parts. While this delegation of responsibility and division of labor greatly simplifies the necessary tasks of research, engineering design, and equipment fabrication, there remain certain central problems of insuring appropriate integration of the parts to the whole functional product.

It is also a fact that more complex machine functions often require the use of many more pieces of equipment and assemblies, utilizing virtually a myriad of components. This is important because, in the case of military weapons systems, only one faulty part in one unit may result in catastrophic system failure. The design of an operationally reliable system has become such a critical problem, as the complexity of the machine systems has increased, that the "systems engineer" has emerged on the American labor market as a new occupational group and the term "reliability" has become almost a new household word in the field of engineering.

BASIC SYSTEMS RELIABILITY CONSIDERATIONS

The importance of overall "systems" considerations can be shown by the simple fact that in a missile system composed of one hundred components in series, each of which was of the widely accepted quality level of 99% reliability, the overall reliability would turn out to be only $36.5\%^{2}$. If the same missile were composed of one thousand components of 99% reliability, the overall reliability would then be only 0.02%. Thus, in order to achieve an overall reliability of only 80%, a missile of some four thousand components could tolerate not more than one failure in eighteen thousand for each component. These figures illustrate the high reliability standards required in the design of modern complex machine systems. For example, it was recently recommended that absolute reliability standards for components should be raised to the point where not more than one out of 10,000 or one out of 100,000 units may be permitted to fail. It was also suggested that safety factors be raised from 1.5 or 2.0 to 10.0 for most missile equipments.

In dealing with the components of a machine system, it may be naively assumed that the old adage "a chain is as strong as its weakest link" applies to this situation and that each component should be brought up to the necessary required overall reliability level. However, the basic reliability formula indicates that the overall reliability of the system is *not* the average of the parts reliabilities but their product. This "product rule" method of determining system reliability is, of course, a simplified general statement which assumes (1) that the failure of any one part results in system failure, and (2) that

the parts failures are independent of each other. To say this another way, the effort required to achieve a given level of overall reliability increases exponentially with the number of equally reliable components which are added to the system. Thus, it is not too difficult to understand why it sometimes seems as though very complex machine designs may never become very reliable and serviceable under actual operational conditions. This discussion also illustrates the need for a continual effort to simplify engineering designs by reducing the total number of components which tend to degrade system reliability.

It has usually been assumed theoretically, and found to be the case empirically with some electronic unit failures, that the rate of failures is fairly constant throughout the operational life of the units. This, of course, excludes consideration of the higher rate of failure which may occur during the early failure period or the wear-out period. Therefore, as a function of time, the probability of failure-free operation would decrease exponentially. This basic relationship may be described by the following function:

$$P(t) = e^{-\frac{T}{m}}$$

This particular estimate of part reliability indicates that the probability of successful performance of a unit function is dependent upon one variable (t, which is a time interval) and one constant (m, which is mean life or mean time between failures, if and when operational readiness can be restored after failure).

Assuming this simple exponential function is valid, the reliability of any two subsystems could then be compared according to their mean lives (since that is the only parameter in the function). By specifying an index of reliability (utilizing the term, mean life), it is then often possible to develop various types of tests to insure certain minimum acceptable reliability standards under conditions of actual operational use.

Through the use of an overall reliability or system effectiveness formula, management could insure that there would be an appropriate and optimum allocation of developmental effort between the system components. When it is necessary or desirable to obtain increases in overall system effectiveness, this allocation of effort would require detailed decision analyses in a sequential engineering or state-of-the-art situation. Since articulation of probable decision models involves some difficulties in the solution of optimization problems, we will not discuss this particular phase of the problem. Yet, it must be emphasized that this is a vital and rapidly developing area of applied science which should have great impact upon the character of our future research endeavors.

We have now discussed the use of a basic system reliability formula, a method for making quantitative estimates of component reliability, and a basic procedure for the establishment and specification of minimum acceptable values for given situations. Reliability may now be defined as that numerical probability of failure-free system or equipment operation, perhaps during a prescribed time period, but necessarily under certain specified conditions of performance and environment. Failure is defined as the inability of a unit to perform its required function (i.e., a significant drift in the value of a parameter which results in sufficient performance decrement as to preclude successful accomplishment of the specified operational mission or system function). By specification, we mean a detailed description of the product and its performance together with the criteria which must be used to determine whether the product is in conformity with the description. We will next discuss the problem of how the minimum acceptable human factors values necessary for operational needs may be developed.

HUMAN COMPONENTS IN THE SYSTEM

We have been discussing components which relate primarily to non-human aspects of systems analysis. But we know, from previous reports, that a substantial proportion of actual operational system malfunctions has been directly attributable to human error and that this percentage might be further increased if other malfunctions were traced to their cause. These oper-

ational failure reports constitute but one source of information indicating the substantial reduction in systems reliability directly attributable to the human component in certain complex man-machine systems. In regard to research dealing with this human error, one of the more important methodological problems is how best to represent the human variables quantitatively in the mathematical models upon which scientific formulation and solution is predicated.

There have been many discussions in the literature regarding schematic representations of the human component in open or closed loop machine systems.[1,3] There have also been repeated assertions that the reliability level of the human component may be increased by appropriate "human engineering" of equipment, a better division of tasks between men and machines, additional effort in personnel selection, and specialized personnel development such as may be obtained through the use of training devices.

Reliability, in these cases, has generally been in terms of reduction of "human error," increased speed of operation, or other specific laboratory criteria. But, the amount of research and development effort optimally assigned to the human component in the machine system, and the design decisions involving differential allocation of tasks to the man or the machine component, must be predicated upon a more useful, operationally realistic, quantitative relationship of these components to the overall effectiveness estimates of the total system.

The importance of human factors in systems reliability becomes apparent when we consider the basic function of the human component. Whenever man is placed in series with some of the other components of the machine system, he must act as a continual decision maker (of questionable reliability) and the system is, therefore, man controlled. Even when the human component is placed in a parallel open loop feedback relationship to other components and the control is automatic (for example, in a monitoring function), man still exercises some degree of decision making control, hence, contributes to the unreliability of the system. Actually, there is probably no system in which control by the human element is fully excluded.

THE NEED FOR OPERATIONALLY USEFUL RESEARCH

If one useful basic reliability index for electronics components is based upon what has been termed mean life (i.e., the average time to error, or between errors), it would seem that the human component could be similarly described in analogous quantitative terms. For example, the reliability index for a particular human component could be the number of hours of equipment operation without a human error which results in equipment malfunction great enough to interfere with the prescribed system performance. The mean time to failure might be the elapsed time before a gross or significant human task performance error would occur. Another index might be in terms of the training required to achieve a given level of reliability. In any case, there should be some attempt to utilize quantitative terms for the description of human task performance which are similar to those typically employed in the industrial situation.

Such concepts in relation to some current human factors research effort involves a change in basic orientation to research methodology. For example, our research training often emphasizes a rather conservative approach which begins by a thorough searching of all available published material, relies heavily upon historical precedent for the solution of current problems, and pays great attention to the rigid experimental procedures by which hypotheses are tested under carefully controlled conditions. Single variable or limited multi-variable experiments may be conducted under such rigidly controlled conditions that they often seem to be restricted in application solely to the laboratory conditions. It is unfortunate that these research procedures sometimes bear little resemblance to the real operational world. While such procedures may be essential to the development of any basic science, it becomes apparent that such an ap-

proach may not be very fruitful for the solution of industrial problems. Therefore, in the study of variables involving the human factor in systems analysis, an operational analysis approach to research probably should be utilized to a far greater degree than is now the case. In one sense, this may constitute a systematic reality testing of more basic research.

The use of operational analysis of human factors is vitally important in systems analysis because management or executive decisions must be based upon the comparative merits of total equipment or system function. The experimental investigation of human factors variables should also be under conditions where the component is treated as a whole under simulated operational conditions and should include both realistic performance requirements and realistic environmental conditions. This, of course, requires a great deal of ingenuity in experimental design as compared to some more isolated research endeavors.

Thus, operational analysis may be considered to be a type of applied science which takes the whole problem as the phenomenon to be studied rather than just the individual technical parts. It is oriented toward the concept of solving some of the realistic design problems in engineering as they are determined by overall engineering management considerations. The logical approach and basic phases in performing such research are as follows[1]:

1. Problem Formulation

The statement of certain practical problems of engineering design in terms that permit economical and fruitful scientific inquiry. If possible, research products of import to general theory construction may be built-into the experimental design but this should never be at the expense of obtaining useful information for the sponsor. The problem should be stated to a level of specificity which allows the experimenter to answer the operational questions definitively.

2. Reference to a Mathematical Model

One characteristic requirement in such an investigation is the continual use of the criterion of utility. Utility in the application of a mathematical model is derived only when (1) the model is appropriate to the individual investigation and enables more effective interpretation of research results, and (2) the model is congruent, symbiotic, and circumscribed by the overall systems model.

3. Quantitative Estimation of System Components

The values and parameters of the human variables should be obtained under conditions which simulate operational reality as closely as possible. This would include careful consideration of the actual physical, emotional, intellectual, and attitudinal attributes of the personnel who will be called upon to operate the equipment. Consideration should also be given their education, special training, and experience backgrounds. Insofar as possible, conditions of stress, boredom, or distraction which would be encountered in normal operation should be introduced into the experimental situation.

4. Reality Testing

The mathematical models and their elements should be under constant evaluation and modification to improve and insure the validity of their simulation of reality. To foster better description and prediction of operational reality, various portions of the mathematical model are tested by comparing the actual and forecasted results.

5. Alternative Solutions

The research investigator has a basic responsibility to the decision maker to supply sufficient information upon which alternative courses of action may be predicated (to compensate for any significant changes in those operations which are essential experimental controls).

6. Implementation and Feedback

The solutions which are obtained under experimental operational analysis are valid only to the extent that the simulation of actual operational conditions has been appropriate. One of

[1] The authors wish to acknowledge the contributions of Joseph L. Seminara, Engineering Research Section, Picatinny Arsenal for his contributions in the development of these methodological phases.

the best methods of checking this information is by adequate follow-up and feedback procedures from field usage of systems equipment. Thus, the researcher has responsibility both to aid in the implementation of his design recommendations and to fully utilize any feedback information from the field. It is not enough that operational failure or field service reports be routinely transmitted to a specified department in the agency of fabrication; it is essential that adequate dissemination of feedback data be made to all responsible research personnel originating inputs to related systems design.

SUMMARY

The contribution of human factors specialists in engineering for systems reliability is to identify, investigate, then measure those human factors which effect the system under consideration. The extent of such a study should be based upon the importance of the human factors variable in relation to all other system components and the nature of the goal (that is, the kind of decisions which will be based upon the information obtained from such a study). The research procedures are not too different from those used in any other business, military, or industrial research and development program in their orientation towards practical, useful results of immediate importance. It should be emphasized that in the practice of human factors research as applied to systems engineering, analytic formulations based upon common sense, logic, or theoretic approximations should be carefully checked as to their validity in the tradition of the scientific method. This may seem rather elementary, but we all know that in actual practice it is often neglected when studying variables involving the human factor.

It has also been emphasized that in the experimental estimation of human factors variables, they should be treated in a unified manner under carefully simulated operational conditions. However, in the intermediate design and development stages, more detailed or intensive study of the various complex interrelated variables may be warranted in terms of eventual improvement of the total system.

The type of methodological evaluations required in human factors research usually demands acceptable levels of component validity which are obtainable only by full use of each of the several scientific disciplines involved. It may be predicated that, as developmental effort gradually improves the level of machine component reliability in systems, the task of improving the reliability of the less pliable human component will become increasingly important.

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THE STRENGTH OF A MAN

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The strength of one man is shown graphically in 35 different ways. The subject is a healthy adult male in fair physical condition who is described by 20 anthropometric measures.

Strength, the ability to produce tension, is exhibited by man in three different ways. One, in dynamic action, utilizing momentum and ordinarily bringing the entire body to bear in the effort. Two, in static exertion, applying force against an immovable object. Three, in resisting an external power which is directed against the body. The last, termed "breaking strength," is a common limiting factor in man's capacity to withstand accelerative and windblast forces in ejection from high speed aircraft.

In the study of the ejection problem, data on the human strength factor as it applied to this special situation were lacking. Dynamic and static strength data could not be extrapolated with confidence, and existing "breakage strength" data were inadequate. They still are.

It is difficult to compile data on human strength for engineering use because it is not a hard and fast characteristic of human function. Strength is highly susceptible to training; it is largely a function of skill. The range among individuals is known to extend from the extreme weakness of the sedentary individual to the great muscular power found in the athlete. Both are "normal" from the medical viewpoint.

Instead of undertaking the enormous task of measuring large enough numbers of men and women of various age, race and other parameters to present population statistics on strength,—a job which needs to be done—it was decided as a simple expedient to make a careful study of one subject.

The subject chosen was one who could represent a typical pilot, a healthy male adult in fair physical condition—not an athlete in training or a completely sedentary person. The anthropometric description is as follows:

Age	30 years
Height	5 feet 10 inches
Weight	152 pounds
Elbow to wrist	10¼ inches
Shoulder to elbow	12¾ inches
Shoulder width	16¾ inches
Knee to ankle	15 inches
Hip to knee	19 inches
Neck	13½ inches
Chest	33 inches
Forearm	10 inches
Wrist	6½ inches
Waist	30½ inches
Biceps	11¼ inches
Hips	33 inches
Forearm	10 inches
Thigh	19½ inches
Head length	10½ inches
Head height	8½ inches
Head breadth	7½ inches

The subject was arranged in different positions on a heavy wooden plinth as shown in the figures. Segments of the body were considered as lever systems and the body joints under consideration were treated as fulcrums by placing the point of joint articulation directly over the edge of the supporting structure. The position of the "fulcrum" is shown in the figures by an X marked on the subject.

A spring scale was attached to the extremity under test by means of an adjustable strap and snap hook. The spring scale was attached bottom up, so that it weighed itself. The operator gradually increased the load through the spring scale by a pulley system arranged so that the

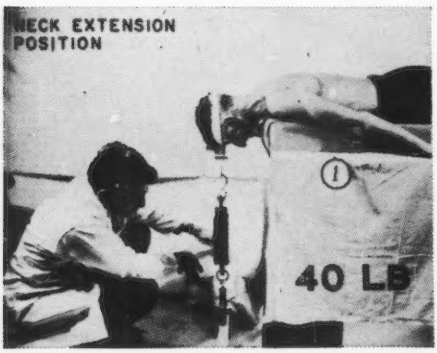
pull was always at right angles to the extremity. As the pull was increased a point was reached at which the subject could no longer maintain his initial position. At this point the tension at the scale fell off rapidly. The maximum reading on the scale was recorded. Three trials were given in each position, and the subject was encouraged to deliver his maximum effort at each trial. The highest score of the three trials was designated the breaking strength score of each position. The breaking strength of the subject in each of the thirty-five positions tested is labeled on each of the figures.

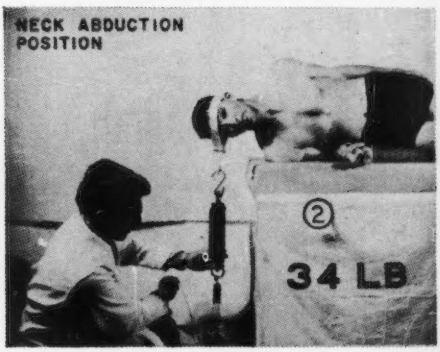
In interpreting the data contained herein, the position of the body should be taken into account, since in some positions the weight of the body part is included in the total resistance to movement.

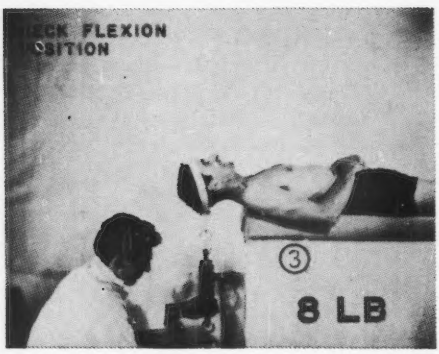
Some human strength characteristics derived in this study are pertinent to engineering design. For example, neck extension strength is fivefold that of neck flexion. Neck flexion is extremely weak. Elbow and knee flexion strength are the same, notwithstanding the relatively more massive musculature of the thigh. The ankle is the strongest joint of the body; slightly stronger in flexion (an unaccustomed movement) than it is in extension. Arm and shoulder strength is very poor when the arm is extended outward; it is especially weak in an overhead position.

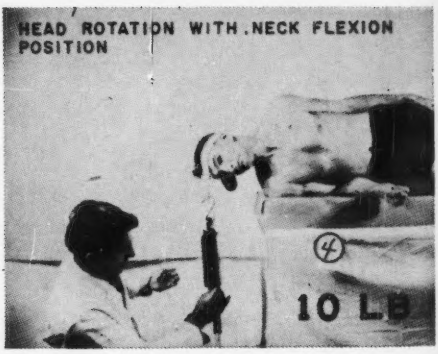
Using the strength and anthropometric data, and making measurements on the figures, it is possible to estimate the subject's approximate breaking strength at almost any point on the body. This is accomplished by computing the proportionate gain or loss in strength as the resistance arm is shortened or lengthened.

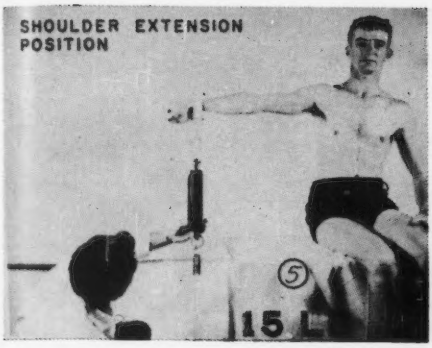
This study was performed in the Aviation Physiology Laboratory at the University of Southern California. The assistance of J. Gordon Wells and Paul T. Butler is gratefully acknowledged.

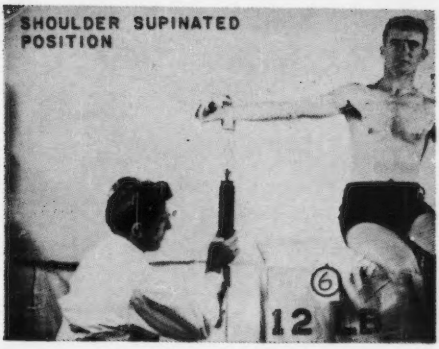






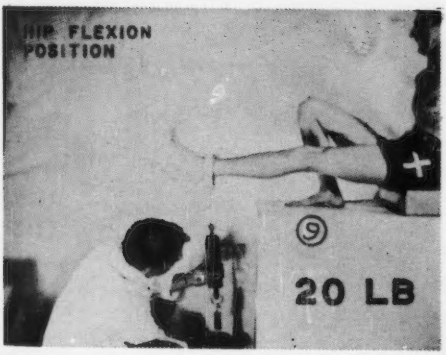



SHOULDER EXTENSION
POSITION
⑤
15 LB

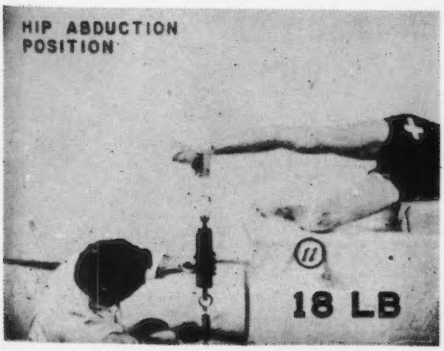

SHOULDER SUPINATED
POSITION
⑥
12 LB

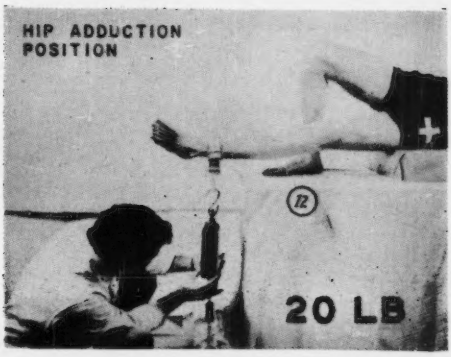
ELBOW FLEXION
POSITION
⑦
60 LB

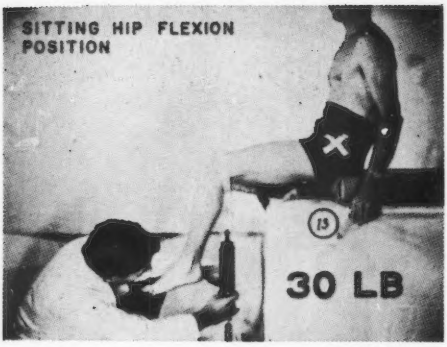
ELBOW EXTENSION
POSITION
⑧
20 LB

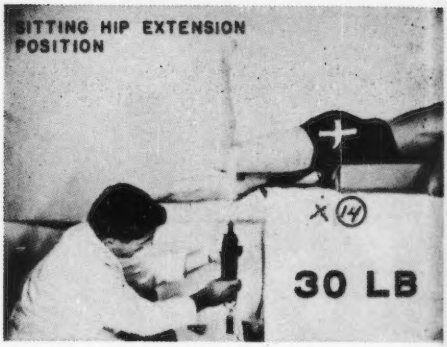

HIP FLEXION
POSITION
⑨
20 LB

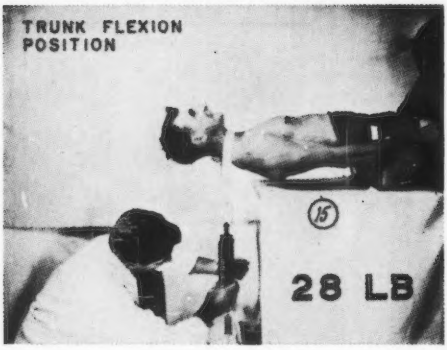
HIP EXTENSION
POSITION
⑩
30 LB


HIP ABDUCTION
POSITION
⑪
18 LB

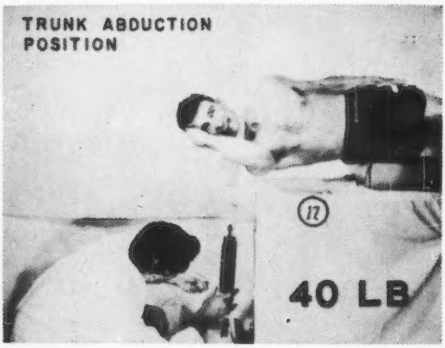

HIP ADDUCTION
POSITION
⑫
20 LB

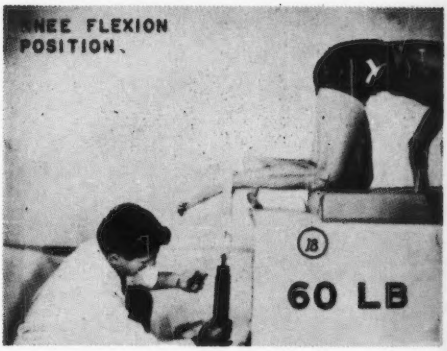

SITTING HIP FLEXION
POSITION
13
30 LB

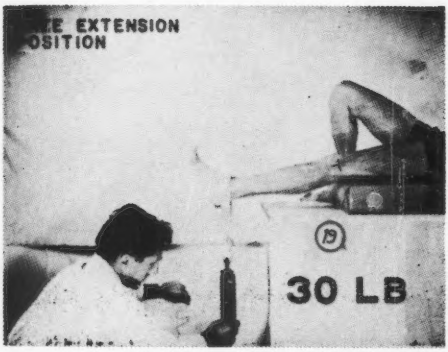

SITTING HIP EXTENSION
POSITION
14
30 LB

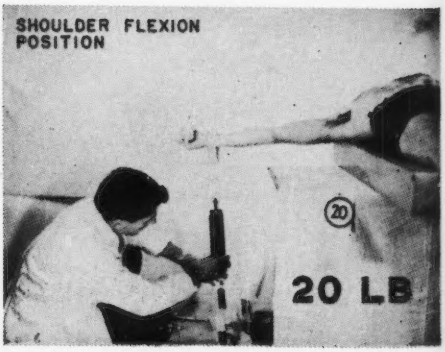

TRUNK FLEXION
POSITION
15
28 LB

TRUNK EXTENSION
POSITION
16
40 LB

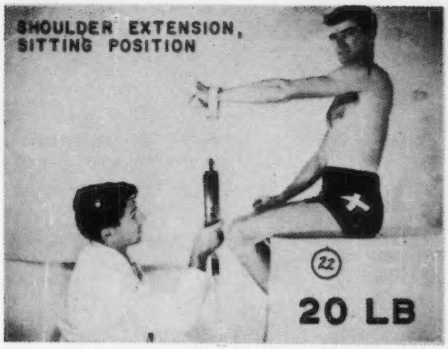

TRUNK ABDUCTION
POSITION
17
40 LB

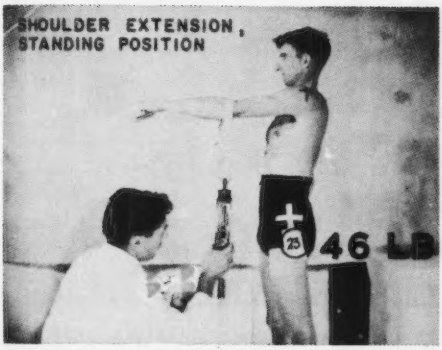

KNEE FLEXION
POSITION.
18
60 LB

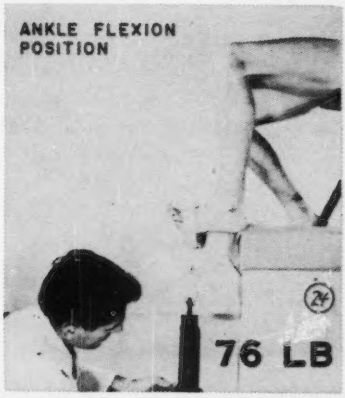

KNEE EXTENSION
POSITION
19
30 LB

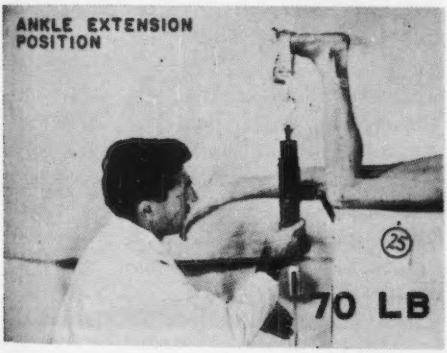

SHOULDER FLEXION
POSITION
20
20 LB

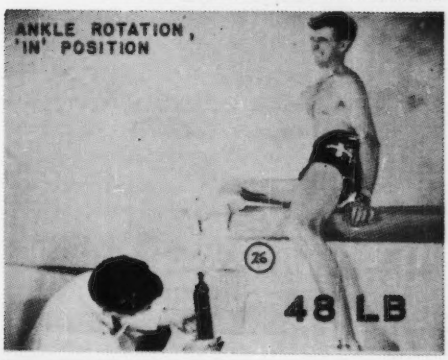
SHOULDER EXTENSION
POSITION
21
14 LB

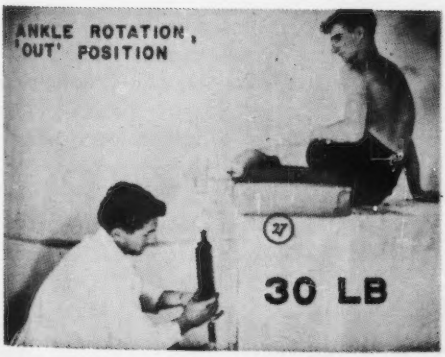

SHOULDER EXTENSION,
SITTING POSITION
22
20 LB


SHOULDER EXTENSION,
STANDING POSITION
23
46 LB

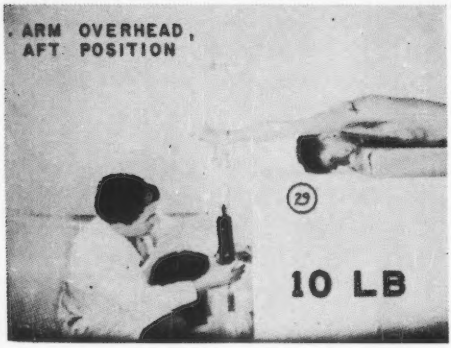

ANKLE FLEXION
POSITION
24
76 LB

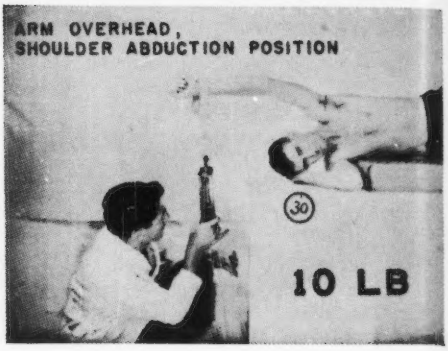

ANKLE EXTENSION
POSITION
25
70 LB

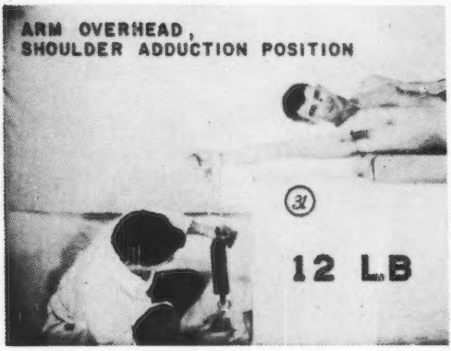

ANKLE ROTATION,
'IN' POSITION
26
48 LB

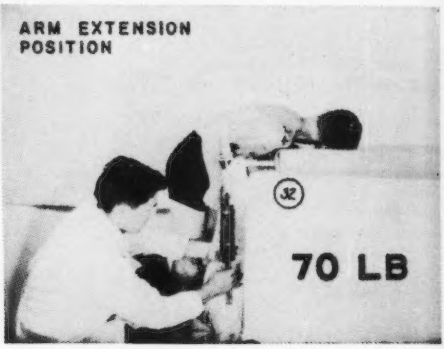

ANKLE ROTATION,
'OUT' POSITION
27
30 LB

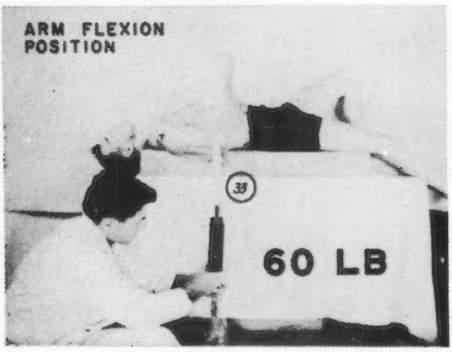
ARM OVERHEAD,
FORE POSITION
28
20 LB

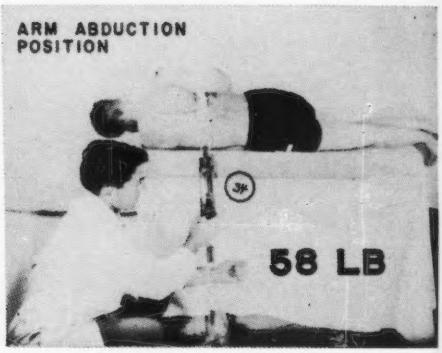

ARM OVERHEAD,
AFT POSITION
29
10 LB


ARM OVERHEAD,
SHOULDER ABDUCTION POSITION
30
10 LB


ARM OVERHEAD,
SHOULDER ADDUCTION POSITION
31
12 LB


ARM EXTENSION
POSITION
32
70 LB


ARM FLEXION
POSITION
33
60 LB


ARM ABDUCTION
POSITION
34
58 LB

ARM ADDUCTION
POSITION
35
40 LB

BOOK REVIEW

PERCEPTION AND COMMUNICATION by D. E. Broadbent

Pergamon Press, New York, 1958. v + 338 pp. Price $8.50.

Perception and Communication is an important contribution to the field of human factors engineering. It is important because it helps place the appropriate perspective on the relation between the findings of theoretical and experimental science, and the data of application. D. E. Broadbent is currently the director of the Applied Psychology Research Unit of the Medical Research Council, Cambridge, England, which has previously been under the successive direction of Sir Frederick Bartlett and N. H. Mackworth. Some of the truly outstanding work of the field of engineering psychology has originated in this center, and Mr. Broadbent's book has not let the tradition down. As an applied experimental psychologist, Broadbent has contributed heavily to an understanding of the perception of voice communication under conditions simulating the practical circumstances of air traffic control through his previously published work on multiple channel listening and listening in the presence of noise. He has studied the relation between visual and auditory inputs and their interactions with skill in detecting signals. He has integrated these experiences with those of other contemporary workers in applied psychology, added a generous input of results from more traditional areas of experimental psychology, and after stirring the lot with a common sense approach to contemporary information theory, has developed a set of conclusions that should be valid for some time to come.

The book offers an excellent review of the pertinent experimental literature. A total of 329 references are cited with emphasis on all phases of auditory perception as well as vigilance and motor skills. The author's approach is perhaps best illustrated by reproducing the topics of the book's table of contents:

Selective Listening to Speech
Verbal and Bodily Response
Introduction: Hearing and Behavior
The Assessment of Communications Channels for Ease of Listening
The Effects of Noise on Behaviour
The General Nature of Vigilance
Some Data on Individual Differences
The Nature of Extinction
Immediate Memory and the Shifting of Attention
The Selective Nature of Learning
Recent Views on Skill
Retrospect and Prospect

But the book is considerably more than a review. It is an interpretation and consolidation of contemporary trends in several related fields from biochemistry to information theory, from Pavlovian conditioning to computers; it is an interpretation of the "state of the art" of man as a machine. For example, the application of filter theory to classical conditioned responses yields the general principle that man is a selective communication channel of limited capacity which responds to sensory events having certain features in common. The filter in such a scheme is a variable which depends on the state of the organism from a physical and physiological standpoint as well as on the probability of the stimulus occurrence. Thus stimuli referring to food have a higher probability of being selected for discrimination of responses if the physiological state of hunger is present — and similarly if the state of conditional probabilities is appropriate, a movement of the required skill to ac-

complish the realignment of a displaced pointer on an instrument will occur when the stimuli incident to misalignment are selectively detected. Variables such as the physical intensity, time elapsed since the last information from a particular class of events entered the limited channel capacity, frequency of event occurrence and sense modality constitute the raw material which the author manipulated to develop substance for his theoretical case. The conclusions are not startling or even slightly disturbing, but seem nearly inevitable with regard to the *Zeitgeist*. However, as Mr. Broadbent points out on page 300: "It is worth listing a few . . . conclusions which are by no means obvious." Some examples from the eight he listed are: "The interference between two tasks will increase as the probability of the stimuli in each decreases: two highly probable stimuli will hardly interfere with one another. . . . The effect of prolonged work and also of continuous distracting stimuli will be greatest at the end of the work-period, and will consist of intermittent failures in the intake of information. Tasks in which a great deal of perceptual anticipation is possible will therefore not show such effects."

The book is omnibus in its viewpoint, including vignettes from the philosophy of science along with gross simplifications of communications theory (from the mathematical standpoint) and the nervous system (from a physiological standpoint). With its seven diagrams, however, it tells a clear story and presents a unified outlook on current human factors problems of noise, vigilance, and motor skill in a manner that only a highly qualified specialist in human factors research and applications could achieve. The book's major drawback is the price of $8.50 for its straight text, one table, and seven minuscule figures.

John Lyman
University of California, Los Angeles

The Authors

RUDOLFS DRILLIS (*The Use of Gliding Cyclograms in Biomechanical Analysis of Movement*) is a senior research scientist in the Research Division of the College of Engineering, New York University, where he has worked since 1950. He was born in Latvia and studied industrial engineering at the Polytechnic Institutes in Riga, St. Petersburg and the University of Latvia. Subsequently, he studied applied psychology at the Herder Institute, and at the University of Leipzig, where he obtained his Ph.D. in 1931. From 1924 to 1944, he was expert, lecturer and professor in Applied Psychology, ergology and biomechanics.

NEIL D. WARREN (*Educational Programs in the Human Factors Area*) is professor of psychology and Head of the Psychology Department, University of Southern California. He is also Secretary-Treasurer of Psychological Services, Inc. He obtained his Ph.D. at USC in 1934 after completing his undergraduate work at the College of the Pacific, and his Master's at USC. He has served as head of the Psychology Department for many years since 1938, with interruptions for service as a major in the Air Corps, 1942-45 and other duties. Since 1952, he has been an instructor in aviation psychology at USC. He is a member of many societies, and is Past President of the California State Psychological Association and the Western Psychological Associations. He is a Diplomate in Industrial Psychology, American Board of Examiners in Professional Psychology. He is the author of numerous journal articles, technical papers, and two books, WORKING WITH PSYCHOLOGY (with F. L. Ruch) and AVIATION PSYCHOLOGY. He has served as a board member of the Human Factors Society, and is presently a member of the editorial board.

HAROLD E. BAMFORD, LEWIS F. HANES, and **SUMMIT E. WILSON** (*Missions for Manned Military Spacecraft*).

HAROLD E. BAMFORD has been concerned with man-machine relations since he received his Ph.D. in psychology from the University of California in 1953. After working for a year on problems of pilot training and proficiency measurement at the Air Force's Basic Pilot Research Laboratory, and for another year on the analysis of conceptual job behavior at the American Institute for Research, he became interested in the area of crew station design. He went to Wright Field as a member of a group of psychologists from the University of Illinois and stayed until 1957, when he joined Ritchie and Associates, Inc. as senior associate. Since then his chief concern has been the organization and application of knowledge about the control of man-operated systems.

Born in New York City, SUMMIT E. WILSON attended both public and private schools (Hunter) there and in Connecticut. As an undergraduate at Antioch College he was enabled to gratify his long-standing interest in aviation and astronautics by securing a temporary appointment to the University of Illinois group at Wright Field. Upon receiving his degree in psychology, *summa cum laude,* from Antioch, he returned to that group in 1956 and in 1957 joined Ritchie and Associates, Inc. as a junior associate. Since then he has devoted his efforts to the control of manned spacecraft and related projects.

LEWIS F. HANES graduated in 1954 from Ohio State University. His concern with man-machine relations came about through his experiences as a pilot and as an intercept director during a tour of duty in the Air Force. Upon his relief from active duty early in 1958 he joined Ritchie and Associates, Inc. as junior associate and immediately became involved in a project on the control of manned spacecraft. He continues his association with military aviation by flying in the Air Force Reserve.

LAWRENCE J. FOGEL (*A New Concept: The Kinalog Display System*) is presently head of the Reliability Group, Engineering Department, Convair-San Diego Division. This group is responsible for assuring the dependable performance of both military and commercial high performance aircraft. The work includes detailed study and design analysis of the various subsystems which make up such aircraft.

Mr. Fogel received the B.E.E. degree from New York University in 1948 and the M.S. degree from Rutgers University 1952, while doing aircraft antenna design work for the Signal Corps Engineering Laboratory. He carried out research in psychoacoustics at Davenco, Inc., and in 1954 was employed by Stavid Engineering, Inc., to accomplish a research study task on cockpit instrumentation under contract to Wright Air Development Center, USAF.

Mr. Fogel has completed additional graduate course work at Polytechnic Institute of Brooklyn, and at UCLA. He has been at Convair since 1956.

GEORGE A. PETERS and **THOMAS A. HUSSMAN, JR.** (*Human Factors in Systems Reliability*).

GEORGE A. PETERS is a consultant in human factors engineering at the West Coast Facility of Psychological Research Associates, Inc. He spent more than six years in the Army (during both the Korean conflict and World War II) as a personnel psychologist, classification and assignment officer, and construction engineer. After further training in psychology and engineering, he worked as senior psychologist of the Alcoholism Study Unit at the Philadelphia General Hospital. Following that, he went to Picatinny Arsenal, where he was employed as a research psychologist in human engineering. He is a member of the American Association for the Advancement of Science, the American Institute of Physics, the American Psychological Association, the Optical Society of America, Phi Kappa Phi, and the Human Factors Society. He has published more than a hundred technical reports, scientific papers, and informative articles in national publications. His most recent effort has been in the preparation of two human factors design manuals for use by missile systems ground support engineers.

THOMAS A. HUSSMAN, JR. has managed the West Coast Facility of Psychological Research Associates, Inc. since it was established late in 1957. His research group has been primarily engaged in the human factors engineering and personnel system development areas. Prior to arriving on the West Coast he directed research projects relating to Air Force intercept director training, tactical decision making, and the experimental evaluation of "human engineered" test equipment at the Washington, D.C. facility of Psychological Research Associates, Inc. A native of Baltimore, Maryland, he received his Ph.D. from the University of Maryland in applied experimental psychology. While serving in the United States Navy he was stationed for three years at the Naval Medical Research Institute as an aviation psychologist. Dr. Hussman is a member of the Aero Medical Association, the Human Factors Society, the Space Medicine Association, the Society of Engineering Psychologists, the American Rocket Society, and the American Psychological Association.

LAURENCE E. MOREHOUSE (*The Strength of a Man*) commenced his studies of physiological factors in human work and sport as an undergraduate student at Springfield College, under Professor Peter V. Karpovich, a student of Pavlov. After completing his doctorate in the physiology of exercise at the University of Iowa and serving as a Fellow in the Fatigue Laboratory at Harvard, Dr. Morehouse went to California where he spent eight years in studies of acceleration physiology at the University of Southern California and served for a time as Chief of Performance Physiology at the Air Force School of Aviation Medicine at Randolph Field. Author of eight books in the fields of human physiology, kinesiology and fitness, Dr. Morehouse now directs the Human Performance Laboratory at the University of California at Los Angeles where he is currently engaged in studies of footwear and seating.

EDITORIAL

ONE FOOT ON THE GROUND

Extra-terrestrial travel is now a more common topic than the weather. Today, everyone is a Jules Verne. Proposal prose is the literary style on our new and shrinking horizon. Astronauts abound in greater numbers than students in Astronomy 1 a few years ago, and the planets and stars are in a fair way of losing their mystery and romance as they become destinations. "Around the Solar System in 80 Units of Time" will be written by some starry-eyed youth of today as a factual account of tomorrow.

Human factors specialists are caught in the spirit of the times, as well we should be, but we must beware of using the challenge of space to escape from other realities of the present. We must not narcoticize ourselves with the dreams of future generations while neglecting the realities of our own. In our planning for the future, we should pose anticipated problems. Then we must determine the technical advances which must be made before proper solutions can be obtained. We must beware of improper solutions using today's hardware and concepts. All of us in the various fields of human factors and associated disciplines must help to make the advances which tomorrow will require.

There are grievous gaps in our human factors arsenal of facts and theories. Few studies in which man is the subject contain an adequate identification of that subject. Too little is known of individual variability. Too few trustworthy techniques are available to guide research programs into economical but fruitful explorations. Generations of scientists have studied the intricate relations of plants and animals to the zonal and seasonal environments without exhausting the field. Much patient and careful work should therefore be anticipated before effective and reliable symbiotic systems are designed. This is but one example. There is much to do and we are in a hurry, but while we point an extra-terrestrial toe toward the future, we must remember that the great leap forward cannot be taken without first having one foot on the ground.

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